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SAUCONITE—A CLAY MINERAL OF THE MONTMORILLONITE GROUP

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ABSTRACT

Zinc-bearing clays, commonly called tallow clays, have long been known, and have been reported from numerous localities, but their mineralogic character has been in dispute since they have been described as mixtures of kaolin and hemimorphite, or less commonly as true zinc clays. A study of excellent material from four regions, and a restudy of old specimens has shown that the zinc clays are distinct minerals belonging to the montmorillonite group, and are analogous to the magnesian clay mineral, saponite. The study presents seven new chemical analyses, and the chemical formulas calculated from them. The optical properties and mineralogical relationships of these minerals to other members of the montmorillonite group are discussed.

A zinc clay from Saucon Valley, Pennsylvania, was analyzed by Roepper in 1875 and named sauconite. A restudy of type material collected by Roepper has shown that the material was representative of the zinc-bearing clays, and therefore the name sacuonite should be accepted for this member of the montmorillonite group.

Zinc-bearing clay materials, commonly referred to as "tallow clays," have long been known, and have been reported from numerous localities, but reports on them have not been in agreement about their character. They have been regarded by some writers to be definite minerals, but more commonly they have been described as mixtures of kaolinitic or related clays and hemimorphite (calamine), and their true relations have therefore long remained problematical; however, as sometimes happens, both schools of thought prove to have been partly right.

Studies of other members of the montmorillonite-nontronite-saponite group, and the ionic substitutions within the group[1] indicated that a true zinc clay analogous to saponite, the magnesian member of the group, was to be expected, and so led to a detailed study of the zinc-bearing clays.

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[1] Ross, Clarence S., and Hendricks, Sterling B., Minerals of the Montmorillonite Group, *Geological Survey, Professional Paper* **205-B** (1945).

Nomenclature

Sauconite

A zinc-bearing clay from the Uberroth Mine, Saucon Valley, near Friedensville, Pennsylvania, was analyzed and named sauconite by Roepper and described by Genth.[2] The material was listed without name by Dana.[3] However, sauconite was included by Chester[4] in the Dictionary of Names and was listed in the Mineralogical Magazine in 1900.[5] A sample of the original material studied by Roepper was made available for study through the courtesy of the Department of Geology of Lehigh University.

Moresnetite

Risse[6] described a zinc-bearing material from Altenberge, near Aachen, in 1865. Material from the type locality was made available for study through the courtesy of the National Museum (Specimen C3426). The zinc mineral in this specimen ranges from light gray to dark blue gray, and forms irregular patches or veinlets associated with a brown material made up of micas and chlorite. With this are fine-grained masses of hemimorphite. The following chemical analyses were made by Risse.

Analyses of Altenberge Morfsnetite

	(1)	(2)
SiO_2	29.26	30.31
Al_2O_3	13.02	13.68
ZnO	37.98	43.41
FeO*	5.61	.27
NiO	0.24	1.14
MnO	tr	
CaO	.76	tr
MgO	.54	
H_2O	11.34	11.37
	98.85	100.18

* Undoubtedly present as Fe_2O_3.

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[2] Genth, F. A., Mineralogy of Pennsylvania: *Second Geol. Survey. Penn.*, p. 120-B (**1875**).

[3] Dana, E. S., A System of Mineralogy, 5th ed., 11th sub. ed., John Wiley & Sons (**1874**).

[4] Chester, A. H., A Dictionary of the Names of Minerals, p. 240, John Wiley & Sons, New York (**1896**).

[5] *Mineralog. Mag.*, **12,** 391 (1900).

[6] Risse, Hugo, Über den Moresnetite, ein neues Zinkoxyd-Thonerdesilikat von Altenberge bei Aachen: *Naturhistorischen Vereines der Rheinlande und Westphalens Correspondenblatt,* No. 1, pp. 98–99, vol. **22,** Bonn (1865).

The following chemical formula has been calculated from Analysis No. (1), the more complete of the two given by Risse. However, No. (2) gives essentially the same formula:

$$(Zn_{2.68}Mg_{.07}Al_{.27}Fe_{.40}Ni_{.02})(Al_{1.19}Si_{2.81})O_{10}(OH)X_{.33}.$$

The summation of ions in octahedral positions (those associated with Zn) in the above formula is 3.44. Only 3 octahedral positions are available within the crystal lattice in minerals of mica-like structure, including those of the montmorillonite group; and hence, this impossible formula shows a large excess of some element—probably zinc as the specimen contains hemimorphite. The Al associated with Si in tetrahedral positions is excessively high for a member of the montmorillonite group, and is high even for a mica.

The following chemical formula of sauconite from the type locality has been derived from analysis No. 10, Table 3—one of the three quoted by Genth[7] when the name sauconite was first published.

$$(Zn_{1.95}Mg_{.12}Al_{.17}Fe_{.58})(Al_{.61}Si_{3.34})O_{10}(OH)_2X_{.33}.$$

The summation of ions in octahedral positions in the foregoing formula is 2.82, and the tetrahedral Al is normal for a member of the montmorillonite group.

The question therefore arises as to the most suitable name for the zinc-bearing clay mineral of the montmorillonite group, which is analogous to saponite. Samples of both the Aachen material (moresnetite), and that from Friedensville (sauconite) have been available for study. Examinations of the Aachen material by means of thin sections, *x*-rays, and differential thermal analysis have indicated the difficulty of securing a pure sample, and this is confirmed by the impossible composition for a member of the montmorillonite group as derived from the original published analyses. On the other hand, these same tests have shown the essential purity of the Friedensville material and the original analyses, although not quite complete, give formulas that conform to those characteristic of members of the montmorillonite group. For these reasons the name sauconite proposed by Roepper and Genth for the mineral from Friedensville, Pennsylvania, seems most suitable for the zinc-bearing clay mineral.

Vanuxemite

Sheppard[8] described a zinc-bearing clay material from Sterling Hill, New Jersey, in 1876 under the name vanuxemite. A sample of type vanuxemite from the Roebling collection of the National Museum

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[7] *Op. cit.*

[8] Sheppard, C. U., Vanuxemite: *Am. Jour. Sci.*, 3rd ser., **12**, 231 (1876).

(Specimen R3920) was made available for study through the courtesy of Dr. Foshag. A microscopic study shows that the material is impure, being composed of two or more materials. An *x*-ray examination gave only extremely weak lines which were definitely not those of sauconite. Tests by means of differential thermal analysis likewise indicated that the material was not sauconite.

Saponite

Sauconite proves to be a member of the montmorillonite group of minerals in which three bivalent zinc ions proxy two trivalent alumina ions in octahedral positions in the lattice structure, and so is entirely analogous to saponite where three magnesium ions play the same role as zinc. For this reason a comparison of the two minerals seems advisable. Saponite was first described by Cronstedt in Sweden,[9] and later by other mineralogists, and particulary by Heddle[10] in Scotland. An examination of the literature on hydrous magnesian silicates suggested that a mineral originally described as griffithite,[11] material from Cahuenga Pass, Griffith Park, Los Angeles, California, was a high-iron saponite. At the time griffithite was described, *x*-ray methods for determining mineral relations were not available and it was tentatively assigned to the chlorite group. However, in a later paper,[12] the authors found that its behavior on dehydration was similar to that of nontronite, another member of the montmorillonite group. The presence of 7.32 per cent of Fe_2O_3 is unusual for a saponite, and although the proxying of Mg by ferrous iron is to be expected, the proportion of FeO in griffithite (7.83 per cent) is the highest that has been reported for any member of the montmorillonite–nontronite–saponite group. The Cahuenga Pass mineral occurs in vesicular cavities in basalt, a widely reported type of occurrence. The optical properties determined by Larsen are given in a following section.

OCCURRENCES OF SAUCONITE

Heywood[13] described zinc clays from the Bertha zinc mines, Pulaski County, Virginia.

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[9] Cronstedt, Axel, Mineralogie, Stockholm (**1758**). English translation by John Hyacinth, An essay toward a system of mineralogy, p. 98, London (**1788**).

[10] Heddle, M. F., The Mineralogy of Scotland; saponite, **29**, 91–102 (1879).

[11] Larsen, Esper S., and Steiger, George, Griffithite, a new member of the chlorite group: *Jour. Wash. Acad. Sci.*, **7**, 11–12 (1917).

[12] Larsen, Esper S., and Steiger, George, Dehydration and optical studies of alunogen, nontronite and griffithite: *Am. Jour. Sci.*, 5th ser., **25**, 1–19 (1928).

[13] Heywood, B. H., A zinc-bearing clay from the neighborhood of the Bertha zinc mine, Pulaski County, Virginia: *Chem. News*. **44**, 207 (1881).

Emmons[14] described zinc clays, locally known as Chinese talc, from Leadville, Colorado, and excellent analyses by Hillebrand were listed. (see Table 3 below.) Later a careful study of zinc clays from the same region was published by Loughlin[15] and the specimens collected by him constitute some of the best materials available for this study.

Branner[16] listed 6 analyses of zinc clays from Arkansas. He believed these to be mixtures of common clays and hemimorphite (calamine), but the compositions correspond so well with material used in this study that it seems probable that Branner's materials were essentially pure sauconite. Adams[17] described "tallow clays" from Arkansas and later these clays were also described by McKnight.[18]

Seamon[19] described zinc clays from Southwest Missouri and listed 15 partial analyses. Most of these correspond closely with the analyzed materials of this paper and it seems probable that the samples of Seamon were essentially pure.

Schönischen[20] described zinc-bearing argillaceous material from Spain in 1863 and gave the following rough analysis: Zn = 21.36, Si 31.50, Al 26.43, H = 18.32.

Chemical Composition

Seven analyses of zinc clays made in the course of this study are given in Table 1. Three analyses made at the time of the original study of sauconite are given in Table 3, and a formula derived from the analysis by Blake is also given. These original analyses show that the material used was seemingly suitable, although the composition was variable. Two excellent analyses of material from Leadville, published in 1886, showed no iron, but otherwise correspond fully with recent analyses. These are also given in Table 3. In the course of the present study one sample from the Roachdale Mine, Lafayette County, Wisconsin, whose analysis is given in Table 4 (No. 15) proved to be a zincian montmorillonite. In the same table, analyses of a typical saponite, of the iron-rich saponite (griffithite), and a typical montmorillonite are given for purposes of comparison with sauconite.

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[14] Emmons, S. F., Geology and Mining Industry of Leadville, Colorado: *U. S. Geol. Survey, Mono.* **12,** 560, 605 (1886).

[15] Loughlin, G. F., The Oxidized Zinc Ores of Leadville, Colorado: *U. S. Geol. Survey, Bull.* **681,** 24–28 (1918).

[16] Branner, John C., The Lead and Zinc Region of North Arkansas (tallow clay), 266, *5th Ann. Rept. Geol. Survey Arkansas for 1892,* Little Rock, Arkansas (**1900**).

[17] Adams, George I., Lead and Zinc Deposits of Northern Arkansas: *U.S. Geol. Survey, Prof. Paper* **24,** 40 (1904).

[18] McKnight, Edwin T., Zinc and Lead Deposits of Northern Arkansas: *U. S. Geol. Survey, Bull.* **853,** 116, 117 (1935).

[19] Seamon, W. H., The zinciferous clays of Southwest Missouri: *Am. Jour. Sci., 3rd ser.,* **39,** 38–43 (1890).

[20] Ingeneur Schönischen zu Neudorf, *Berg und Hütten. Zeit.,* **22,** 164 (1863).

Description of Materials

The samples, numbers 1 to 7, that form the basis of this study, were all examined microscopically, by means of *x*-rays and differential thermal analysis, and several of them were tested by means of the spectrograph. Microscopic examination is more effective for a determination of impurities in sauconite than for most clay materials. The accessory material that is most commonly associated with sauconite is hemimorphite. The index of refraction of hemimorphite is very much higher than that of sauconite, and thus its purity is readily verified. Even when it is too finely disseminated to be resolved by the highest magnifications, this difference in indices causes such marked dispersion of light that it shows up as unusually opaque areas; in fact, this is a useful test for examining clays in general, and permits the detection of very small amounts of gibbsite in kaolinite. The curve given by the differential thermal analysis of sauconite is similar to that of other members of the montmorillonite group at temperatures below about 600°C., but above that point the formation of new zinc silicates gives distinct exothermic reactions, probably due to the formation of willemite.

Sample Number 1, from the Uberroth Mine, Saucon Valley, near Friedensville, Pennsylvania, secured through the courtesy of the Department of Geology of Lehigh University, represents a part of the original material studied by Roepper. It is pale brownish yellow, compact and massive in habit.

Sample Number 2 was collected by G. F. Loughlin of the Geological Survey from the New Discovery Mine, Leadville, Colorado, and was described and pictured by him[21] in a paper on the oxidized zinc ores of Leadville. The material is now a part of the U. S. National Museum mineral collection (No. 91511). The material is laminated with a very perfectly parallel arrangement of the individual micaceous plates, so that there is good parallel extinction in thin section.

Sample Number 3 (Museum also 91511) was collected by Mr. Loughlin from the Yankee Doodle Mine, Leadville, and was described by him in the same paper, as follows: "It has been found in the Yankee Doodle Mine, where it forms a layer about 2 feet thick immediately beneath a thin bed of silicified shale. These occurrences are of sufficient size to be called small ore bodies." The relations are similar to those of the material previously described by Emmons.[22]

[21] *Op. cit.*

[22] *Op. cit.*

Sample Number 4 from the Coon Hollow Mine, about three-fourths of a mile north of the village of Zinc, Boone County, Arkansas, was collected by James S. Cullison in the course of studies of the zinc deposits of Arkansas for the Geological Survey. A large sample comprising several pounds of excellent reddish-brown material was secured.

Sample Number 5 is from the same source as Number 4. It forms nearly pure white, rather porous, layer-like zones in the reddish-brown material. The zinc content is a little high, and *x*-ray examination indicates a small proportion of some unknown impurity, but the material appears to be essentially pure.

Edwin T. McKnight has given the following description of the occurrence of so-called tallow clays in Arkansas.[23]

> The tallow clay in the Zinc district occurs as a filling of seams along the bedding in oxidized zinc deposits. The original mineralized ground was jasperoidized limestone containing disseminated sphalerite which tended to be concentrated along some bedding seams almost to the exclusion of the interstitial jasperoid. Particularly on the bedding planes but also along irregular cross-cutting fractures, flat vugs were formed that contained crystalline sphalerite and a pink coarsely-crystalline form of dolomite. In the oxidation the sphalerite and dolomite were leached or converted in place to hemimorphite which to some extent replaced the dolomite as pseudomorphic crusts. The tallow clay was deposited in the bedding seam vugs that were originally present or that formed through leaching of the sphalerite and the jasperoid.

Sample Number 6 from the Liberty Mine, near Meekers Grove, Wisconsin, was collected by Allen V. Heyl, Jr., while engaged in studies of the zinc deposits of that area for the Geological Survey. It consists of reddish-brown material, with narrow lenses of iron oxide that were scraped away before analysis.

Mr. Heyl describes the occurrence of the material as follows:

> All three samples (including the zincian montmorillonite) of the zinc tallow clay occurred filling vugs in the primary veins in the zone of incipient oxidation within the area of the fluctuating water table. All the sphalerite in the veins was essentially unaltered, having only a thin film of smithsonite upon it. Apparently, the zinc in the clay came not only from the oxidation of the bordering ore vein, but to a large extent carried down and redeposited as sauconite at the water table.

Sample Number 7, from the same mine as Number 6, was collected by Charles H. Behre, Jr., of the Geological Survey. It is somewhat darker colored than Number 6, owing to a slightly higher iron content.

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[23] Personal communication.

TABLE 1. CHEMICAL ANALYSES OF SAUCONITE

	Friedensville, Pennsylvania	New Discovery Mine, Leadville	Yankee Doodle Mine, Leadville	Coon Hollow Mine, Arkansas		Liberty Mine, Meekers Grove, Wisconsin	Plattesville Dist., Wisconsin
				Brown Clay	White Clay		
	1	2	3	4	5	6	7
SiO_2	34.46	35.95	37.10	33.40	33.59	38.59	38.70
Al_2O_3	16.95	6.57	14.18	7.45	6.01	13.36	16.29
Fe_2O_3	6.21	2.36	.30	1.73	.28	3.41	3.91
MgO	1.11	1.26	1.10	.78	.70	1.18	1.62
MnO	—	.04	.02	tr.	.12	—	.06
ZnO	23.10	33.70	28.19	36.73	39.33	23.50	22.48
CaO	—	.62	1.22	1.92	1.90	.94	tr.
Na_2O	—	.44	.24	.22	.13	.01	.43
K_2O	.49	.10	.13	.27	.07	.18	.32
CuO	—	—	.02	.13	.10	—	—
TiO_2	.24	.07	tr.	.15	.03	.31	.30
H_2O-	6.72	11.34	8.82	9.78	10.68	10.39	7.50
H_2O+	10.67	7.24	8.90	7.14	6.98	8.05	8.38
	99.95	99.69	100.22	99.70	99.92	99.92	99.99

No. (1) J. G. Fairchild—analyst.
No. (2) J. G. Fairchild—analyst.
No. (3) M. K. Carron—analyst.
No. (4) M. K. Carron—analyst.
No. (5) M. K. Carron—analyst.
No. (6) M. K. Carron—analyst.
No. (7) S. H. Cress—analyst.

TABLE 2. CHEMICAL FORMULAS FOR SAUCONITE

(1) $(Zn_{1.48}Mg_{.14}Al_{.74}Fe'''_{.40})(Al_{.99}Si_{3.01})O_{10}(OH)_2X_{.33}$
(2) $(Zn_{2.40}Mg_{.18}Al_{.22}Fe'''_{.17})(Al_{.53}Si_{3.47})O_{10}(OH)_2Ca/2_{.13}Na_{.09}$
(3) $(Zn_{1.85}Mg_{.14}Al_{.79}Fe'''_{.02})(Al_{.70}Si_{3.30})O_{10}(OH)_2Ca/2_{.23}Na_{.05}$
(4) $(Zn_{2.64}Mg_{.11}Al_{.12}Fe'''_{.13})(Al_{.73}Si_{3.27})O_{10}(OH)_2Ca/2_{.40}Na_{.04}K_{.04}$
(5) $(Zn_{2.89}Mg_{.10}Al_{.04}Fe'''_{.02}Mn_{.01})(Al_{.65}Si_{3.35})O_{10}(OH)_2Ca/2_{.40}Na_{.02}K_{.01}$
(6) $(Zn_{1.54}Mg_{.15}Al_{.78}Fe'''_{.23})(Al_{.61}Si_{3.39})O_{10}(OH)_2Ca/2_{.18}K_{.02}$
(7) $(Zn_{1.23}Mg_{.41}Al_{.73}Fe'''_{.43})(Al_{.80}Si_{3.20})O_{10}(OH)_2X_{.33}$

(1) $\Sigma=2.77$
(2) $\Sigma=2.90$
(3) $\Sigma=2.71$
(4) $\Sigma=3.00$
(5) $\Sigma=3.06$
(6) $\Sigma=2.70$
(7) $\Sigma=2.80$

Σ represents the ions in octahedral positions. Ca/2 represents Ca divided by 2, a necessary procedure for a bivalent exchangeable base.

TABLE 3. CHEMICAL ANALYSES OF SAUCONITE

	Friedensville, Pennsylvania			Lower Waterloo Mine Leadville, Colorado	
	Pale yellow, white	Ochre yellow	Pale yellow		
	8	9	10	11	12
SiO_2	48.42	46.45	41.36	35.97	35.33
Al_2O_3	10.66	7.41	8.04	8.81	10.38
Fe_2O_3	3.85	14.28	9.55	—	—
MgO	—	.97	1.02	.80	.71
CaO	2.42		—	1.87	1.62
ZnO	26.95	22.86	32.34	35.40	33.05
Na_2O	—	—	—	—	—
K_2O	—	—	tr.	—	—
H_2O-	—	—	—	7.20	7.42
H_2O+	7.06	6.75	7.76	10.26	11.64
	99.88	98.69	99.97	100.31	100.15
	(Dehydrated at 105° C.)				

(8) W. Th. Roepper—analyst.[1]
(9) W. Th. Roepper—analyst.[1]
(10) J. M. Blake—analyst.[1]
(11) W. F. Hillebrand—analyst.[2]
(12) W. F. Hillebrand—analyst.[2]

[1] *Op. cit.*
[2] *Op. cit.*

Formulas based on previous analyses of sauconite

(10) $(Zn_{1.95}Mg_{.12}Fe_{.58}Al_{.17})(Al_{.61}Si_{3.39})O_{10}(OH)_2X_{.33}$
(11) $(Zn_{2.46}Mg_{.10}Al_{.38})(Al_{.61}Si_{3.39})O_{10}(OH)_2Ca/2_{.40}$
(12) $(Zn_{2.32}Mg_{.10}Al_{.55})(Al_{.62}Si_{3.38})O_{10}(OH)_2Ca/2_{.34}$

TABLE 4. ANALYSES OF SAPONITE AND MONTMORILLONITE

	Saponite[1] Ahmeek Mine, Michigan	Iron Rich Saponite[2] (Griffithite), California	Zincian Montmorillonite, Wisconsin	Montmorillonite, Booneville,[3] Mississippi
	13	14	15	16
SiO_2	42.99	39.64	40.62	50.53
Al_2O_3	6.26	9.05	21.79	19.31
Fe_2O_3	1.83	7.32	9.73	7.25
FeO	2.57	7.83	—	—
MgO	22.96	15.80	1.67	2.60
MnO	.11	—	.04	.02
ZnO	—	—	3.82	—
CaO	2.03	2.93	.10	.72
Na_2O	1.04	.71	.88	.41
K_2O	tr.	none	.10	.34
TiO_2	—	—	.66	.75
P_2O_5	—	—	—	.15
H_2O-	13.65	12.31	8.92	10.66
H_2O+	6.85	4.90	11.59	7.90
	100.29	100.49	99.92	100.64

(13) Helen E. Vassar—analyst.
(14) George Steiger—analyst.
(15) J. G. Fairchild—analyst.
(16) J. G. Fairchild—analyst.

[1] Palache, C., and Vassar, H. E., Some minerals of the Keweenawan copper deposits, 3. Saponite: *Am. Mineral*, **10**, 417–418 (1925).

[2] Larsen, Esper S., and Steiger, George, *op. cit.*

[3] Ross, Clarence S and Hendricks, Sterling B., *op. cit.*, p. 34.

Formulas for saponite and montmorillonite

(13) $(Mg_{2.69}Al_{.21}Fe'''_{.10})(Al_{.54}Si_{3.46})O_{10}(OH)_2Ca/2_{.47}Na_{.16}$
(14) $(Mg_{1.88}Fe''_{.52}Fe'''_{.44}Al_{.04})(Al_{.81}Si_{3.19})O_{10}(OH)_2Ca/2_{.50}Na_{.11}$
(15) $(Al_{1.28}Fe'''_{.58}Mg_{.20}Zn_{.22})(Al_{.76}Si_{3.24})O_{10}(OH)_2Na_{.12}Ca/2_{.02}K_{.01}$
(16) $(Al_{1.40}Fe'''_{.40}Mg_{.28})(Al_{.28}Si_{3.72})O_{10}(OH)_2Na_{.12}Ca/2_{.06}K_{.03}$
(13) $\Sigma=3.00$ (15) $\Sigma=2.28$
(14) $\Sigma=2.88$ (16) $\Sigma=2.08$

The formulas presented have been calculated according to a procedure described in another paper.[24] *X*-ray studies have given definite information about the role of different ions in the crystal structure and have shown that Zn, Fe‴, Fe″, Mn, and essentially all Mg should all be assigned to octahedral positions in the crystal lattice. The Al occupies both octahedral positions, and tetrahedral ones where it proxies Si in part; the distribution between the two positions being such as to balance the valence. The only variable that is not fully determinable from the analyses is that of the interlayer ions, essentially Ca, Na, and K. However, H may proxy bases in interlayer positions and is especially likely to be present in a clay formed in the presence of oxidizing sulfides, as were some of the sauconites. Analyses Nos. 1 and 7 in the foregoing tables are obviously low in bases, and in these the interlayer ions are assumed to have the ratio, tetrahedral ions : exchangeable bases$=4{:}0.33$. This value of $X_{.33}$ has been found to be a close approximation in a large number of members of the montmorillonite group. There is some variation in the proportion of exchangeable bases; small amounts of impurities may appear among the ions that are characteristically replaceable, but they would have only a small effect on the distribution of Al between tetrahedral and octahedral positions in the crystal lattice.

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[24] Ross, Clarence S., and Hendricks, Sterling B., Minerals of the Montmorillonite Group, *Geological Survey, Prof. Paper* **205-B** (1945).

In the formulas of sauconite (Nos. 1 to 7, 11 and 12) the Al in tetrahedral positions ranges from about 0.50 to 1, and in most of them it lies between 0.60 and 0.80. In formula No. 1 the tetrahedral group ($Al_{.99}Si_{3.01}$) is like that in muscovite and is high for a mineral of the montmorillonite group. Most of the sauconite formulas contain more Al than some of the montmorillonites, in which Al may approach 0 while Si may become approximately 4. Zinc is the dominant ion in octahedral positions in all the formulas calculated and ranges from 1.50 to nearly 2.90, varying reciprocally with Al and Fe and to a lesser extent with Mg. The total number of ions in octahedral positions, indicated by Σ, ranges from 2.70 to 3.06. Only 3 octahedral positions are available; No. 5, with $\Sigma=3.06$, probably contains a little excess of bases, possibly in hemimorphite, though none was revealed by *x*-ray study. The total of octahedral ions is low in members with the most trivalent ions (Al and Fe‴), and high in those composed dominantly of bivalent ones. This is to be expected, as members of the montmorillonite group composed dominantly of trivalent octahedral ions contain from 2 to about 2.2 such ions per one-half unit cell, and those composed of essentially bivalent ones contain about 3 such ions.

The formulas for sauconite are entirely analogous to that of saponite No. 13, with bivalent Zn playing the same role as bivalent Mg. The iron-rich saponite (griffithite) differs from normal saponite in its very high content of ferrous and ferric iron, but gives the same curve by differential analysis.

OPTICAL PROPERTIES

Clay materials of the montmorillonite group present difficulties that might seem insuperable in the determination of their optical properties, but methods are available by which some of these can be approximated. There are, however, a number of variables that affect the results, and so a definite procedure must be followed if comparisons of indices of refraction are to have significance. The indices of refraction may be determined on definitely oriented aggregates or on films in which the micaceous clay particles had assumed essentially parallel positions. To secure good parallel orientation in such clay films, it is necessary to have essentially complete dispersion of the individual micaceous plates that constitute the clay minerals. This dispersion in general does not occur where calcium, the normal exchangeable base of clays, is present. The first step, therefore, is the substitution of sodium for calcium as the exchangeable base, followed by washing the clay suspension entirely free from excess salts. Such suspensions, in general, give excellently oriented films on drying. When these are broken up or sliced into minute ribbons, optical measurements can be made; however, when the clays stand in immersion oils, these oils slowly permeate the materials and raise the indices of refraction by displacing occluded air. Determinations of the true indices, therefore, demand complete permeation with the particular index liquid that matches the index of the mineral. Another variable is the water film between each pair of molecular sheets, which changes the spacing. The material used in this study was first moistened with acetone; a nonvolatile index oil was then added, time (24 hours) was allowed for the acetone to evaporate, the old oil was taken up with filter paper, new oil of the same index was added, and then the preparation was allowed to stand till permeation was complete. The indices determined on 4 samples of sauconite and the indices determined by Larsen[25] for saponite from the Ahmeek Mine, and for griffithite are given in the following table.

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[25] Palache and Vassar, *op. cit.*
Larsen and Steiger, *op. cit.*

TABLE 5. OPTICAL PROPERTIES

Sauconite	Indices of Refraction			Optical Character	Color (Ridgeway)
	α	β	γ		
(1) Friedensville, Pennsylvania	1.575		1.615	(—)	Warm buff 17′ O-Y, d
(2) New Discovery Mine, Colorado	1.550		1.592	(—)	Avellaneous 17‴ O-Y, b
(4) Coon Hollow Mine, Arkansas	1.564		1.605	(—)	Pinkish Cinnamon 15″ Y-O, b
(6) Liberty Mine, Wisconsin	1.570		1.605	(—)	Drab 17⁗ O-Y
Saponite					
Ahmeek Mine, Michigan	1.527	1.525	1.590	(—)	Light buff 17′ O-Y, f
Cahuenga Pass, California (Griffithite)	1.485	1.569	1.572	(—)	Pleochroic, pale yellowish—olive green—brownish green

RARE COMPONENTS

Samples of sauconite from the New Discovery Mine, Leadville, Colo., and the Liberty Mine, Benton, Wis., were examined by means of the spectrograph by K. J. Murata of the Geological Survey.

The material from the Liberty Mine contained Pb, Li, B, Cu, V, and Ni in amounts ranging from traces to less than 0.01%. The sauconite from the New Discovery Mine contained Cr, Ba, Mn and Ni between 0.1 and 0.01 per cent; and Sr, Li, and Cd questionable. The sauconite from the Coon Hollow Mine, Ark., was expressly tested for Cd, and none was recognized; if present at all it is less than 0.01 per cent. An impure zincian montmorillonite from Goodsprings, Utah, was found to contain about 1 per cent of Ni, a few tenths of a per cent of Co and Cu, a few hundredths of a per cent of Cr and V, and no Cd.

RANGE IN COMPOSITION IN THE MONTMORILLONITE GROUP OF CLAY MATERIALS

The minerals of the montmorillonite group are characterized by a very wide range in the ions which can proxy Si or Al within the crystal lattice. In tetrahedral positions Al proxies part of the Si (so far as known 1 or less ions out of a possible 4 in the one-half unit cell); and in octahedral positions an unusual number of ions can proxy Al. Other variables in the chemical composition are the interlayer replaceable ions, which may include almost any of those available in the environmental system; the proxying of OH by F as in the micas; and wide variations in amount of interlayer water. The ions that are known to occupy octahedral positions completely or almost completely are Al, ferric iron, Mg, Cr, and Zn; those which are present in essential but not dominant proportions are ferrous iron, Li, Mn, and Ni.[26] Titanium is known to play the role of Al in the micas, but its ready hydrolysis tends to remove it from the lattice structure of a clay mineral and deposit it as one of the materials known as leucoxene. Vanadium is believed to be an important component in the clay materials associated with some vanadium-bearing phosphate beds, just as it is in roscoelite, but it has not been possible to secure material suitable for chemical analysis.

The state of oxidation of Mn, which is sparingly present in some members of the group, is not directly determinable, but the higher state of oxidation of the iron and the lavender-pink color of some of the manganese-bearing montmorillonites indicates that small amounts (0 to a maximum of 0.18 per cent) are normally present in the higher state of oxidation. The strong tendency of manganese to form oxides (many clays contain small aggregates of manganese oxide) probably limits the amount that enters the crystal structure. Only under very unusual conditions would a clay with essential quantities of MnO be expected to form. Chromium, which is present in spectrographic amounts in a few samples, is a dominant constituent in volchonskoite from Russia and in essential amounts in some beidellites described by Serdiuchenko[27] from the same region. The spectrographic traces of Ba, Pb, and Sr are probably present as replaceable bases.

The Boone County, Arkansas, sauconite came from an area characterized by cadmium, and it was rather surprising that none was revealed by the spectroscope. Cadmium, however, has a large ionic radius (about 1.00 Å) as compared to .57 for Al and .75 for Mg, and it is possible that it is too large to enter the lattice of members of the montmorillonite group in any essential proportions. The role of such elements as Cu and B, which have been reported in very small proportions, is problematical. Only traces of Co have been recognized in clay minerals, but the chemical relationships of cobalt and the ionic radius of Co (.77 Å) suggests that a cobaltian clay would be possible in a suitable environment.

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[26] Ross, C. S., Hendricks, S. B., *op. cit.*

[27] Serdiuchenko, D. P., Chrome-nontronites and their genetical relations with the serpentines of the northern Caucasus: *Soc. russe mineralogie Mem. 2nd ser.*, **62,** 376–390 (1933).

A GRAPHIC SOLUTION FOR CERTAIN PROBLEMS OF LINEAR STRUCTURE

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Abstract

The coordinates of linear structure in rocks without foliation or platy flow structure can be determined stereographically from field measurements of its traces on several outcrop surfaces. The method is based on a simple geometrical concept involving linear elements of ideal cylindrical shape, and its application is limited to minerals with roughly equi-dimensional cross-sections. The departure of the graphic results from the theoretical ideal is evaluated by statistical treatment. The Storm King granite at Bear Mountain, New York, furnishes illustrative examples.

Introduction

The problem of finding the coordinates of linear structure in rocks devoid of foliation or platy flow structure frequently presents difficulties in the field. The attitude of lineation on outcrop surfaces may be quite misleading, since it merely represents the visible elongation of intersection figures between random plane surfaces and three-dimensional rod or pencil shaped bodies.

The Storm King granite in the interior of the Bear Mountain intrusive in the Hudson Highlands of New York is a case in point. This medium-grained flow rock has a well-developed gneissoid structure produced by the linear alignment of hornblende elements of rather stout prismatic habit. Only outcrop surfaces oriented essentially perpendicular to this linear structure have an even granular appearance without noticeable mineral parallelism. On all other exposures the hornblende is drawn out in parallel streaks. If we assume this linear structure to be plunging 20° toward N45°E, an exposure surface striking approximately N45°W and dipping about 70°SW would fail to show any distinct elongation of the hornblende sections. On the other hand, a surface of the same strike but with a dip of 40°SW may produce elongate sections of the linear elements whose axes of elongation have a pitch of 90°. The true plunge of linear structure (20°), then, can be measured directly only on a vertical outcrop surface striking N45°E, i.e. parallel to the linear structure. Considering the thick stubby shape of the hornblende elements, it becomes even more difficult to determine the coordinates of linear structure accurately owing to insufficient variation in the shape of the streaks on the many exposure surfaces of widely different orientation.

Petrofabric analysis, though tedious and time-consuming, will give adequate results, provided a reasonably constant relation exists between the preferred dimensional orientation of the linear elements and their optical or crystallographic directions. Referring to the example cited above, the larger quartz grains possess the same dimensional alignment as the hornblende, but their optic axes have essentially random orientation.[1] Standard petrofabric methods, therefore, cannot be employed successfully as far as the dimensional orientation of these quartz elements is concerned.

An acceptable solution of this problem can be obtained from field measurements on at least 6 outcrop surfaces by use of the stereographic projection. The accuracy of the results increases with the number of surfaces measured and the diversity of their space orientation. Strike and dip of each surface as well as pitch of lineation must be determined. The orientation of surfaces which do not show any preferred direction of mineral elongation serves as a useful check on the graphic solution.

DEFINITIONS

Structural geologic terminology has been used in a different sense by different authors. Some of the more controversial terms appearing in this paper are therefore defined.

The trend in space of a line is defined by two angles:

Bearing—the projection of a line onto the horizontal plane, measured from the geographical north (Bucher, 1944, p. 195), and

Plunge—the angle from the horizontal to the line, measured in a vertical plane (Billings, 1942, p. 44).

The coordinates of a line *within* a given plane are defined by the strike and dip of that plane, and by the

Pitch—the angle that the line makes with a horizontal line in that plane (Billings, 1942, p. 135).

Linear structure—parallel alignment of the long axes of elongate mineral grains or other linear elements in a rock.

Lineation[2]—parallel alignment of elongate traces of linear elements on an exposure surface.

Linear flow structure or flow lines—linear structure interpreted as the result of flow in igneous rocks.

Linear elements—in this case, the individual elongate mineral grains responsible for the linear structure.

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[1] This unusual feature will be discussed in detail by the writer in a forthcoming paper on the Storm King granite at Bear Mountain, N.Y.

[2] The writer believes that a clear distinction should be made between the parallelism of the axes of linear elements in a rock and the parallel alignment of the elongate traces of such elements on an exposure surface. Although the terms "linear structure" and "lineation" have been used interchangeably by most authors (Billings, 1942, p. 300), it is proposed to limit the concept of "lineation" to the elongate traces of linear elements on exposure surfaces.

Planar structure or foliation—arrangement of mineral grains in parallel layers (planes or curved surfaces) with or without linear alignment of the elements.

Platy flow structure or flow layers—foliation interpreted as the result of flow in igneous rocks.

Geometrical Principle

The proposed graphic method is based on the application of a simple geometrical principle. Figure 1 illustrates the relationship between a cylinder E and a plane P cutting it at any given angle, except essentially parallel or perpendicular to the cylinder axis XX'. The intersection is seen to be an ellipse S of varying eccentricity depending on the angle of intersection. Plane N, perpendicular to plane P and containing the long diameter YY' of ellipse S, also includes the cylinder axis XX'. This plane of construction will henceforth be referred to as the N-plane. Two or more N-planes erected on cutting planes of different orientation, then, must intersect in a single line, namely the cylinder axis XX'.

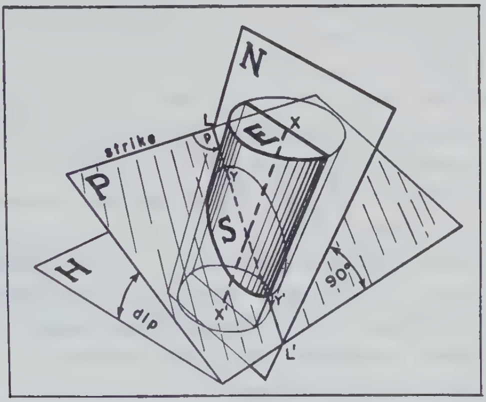

Fig. 1. Geometrical relations between an ideal cylindrical element and an outcrop surface.

XX' = axis of linear element
LL' = lineation on outcrop surface
p = pitch of lineation

Substituting geological concepts for the geometrical terminology we find that

E is a linear element of ideal cylindrical shape,
P is an outcrop surface,
S is the elongate trace of the linear element on the outcrop surface P,
YY' is the trend of mineral elongation or lineation LL' in surface P, having a pitch of p degrees,
XX' is the sought attitude of the linear structure in the rock.

The strikes and dips of several outcrop surfaces together with the angles of pitch defining the trends of lineation are known from field measurements. The corresponding *N*-planes are plotted on a stereographic projection net and their common line of intersection representing the desired attitude of linear structure is determined graphically.

The two principal limitations of this method as applied to geological field conditions now become quite evident. The presence of foliation or platy flow structure would render the basic concept inoperative, since the mineral elongation observed on the outcrop must be derived from sections of individual linear elements and cannot represent linear traces of mineral layers. Also the shape of the linear elements should approach, at least roughly, the shape of a cylinder. Minerals of prismatic habit with more or less equi-dimensional cross-sections, such as quartz, hornblende, augite, etc., are best for this purpose. Mica flakes and tabular feldspar crystals, on the other hand, are not suitable.

STEREOGRAPHIC CONSTRUCTION

A Wulff meridian stereonet (Bucher, 1944, p. 193, footnote) is used for the graphic solution of the problem. For field purposes a net of 4.5 inches diameter drawn to 2° intervals should be mounted on plywood or heavy cardboard. The data are plotted on a sheet of tracing paper or cellulose acetate placed over the stereonet. A 5×5 inch sheet of 10-point (.010 inches thick) transparent cellulose acetate is superior to tracing paper overlays. The acetate is not only more rigid and transparent than the best of papers, but also has less tendency to warp and wrinkle under diverse climatic conditions. Furthermore the field geologist need carry only a single sheet. An ordinary fountain pen, preferably with a fine writing point, is adequate for drawing all construction lines on the overlay. After obtaining the desired data the ink lines can be washed off with water and the acetate used over again.

The method of plotting follows the conventional procedure of lower hemisphere projection discussed by Bucher (1944). The consecutive steps of construction involved in this particular problem are reviewed for the benefit of those who do not have ready access to appropriate references such as the one cited above.

The acetate sheet is placed over the stereonet and attached by a pin piercing the center of the net about which the overlay must be free to rotate. A circle of the net diameter should be permanently inscribed on the acetate with a pair of dividers and reference ticks should be placed at the North and South poles in the same manner.

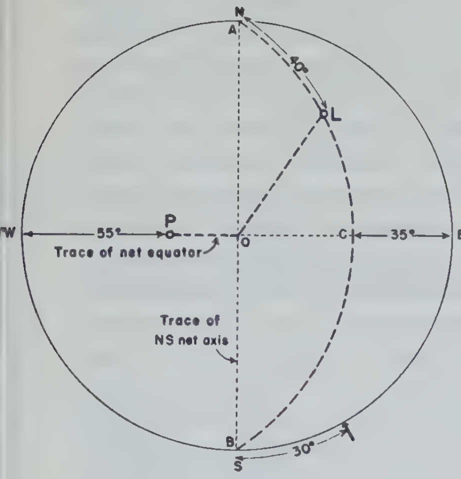

FIG. 2. Stereographic plot of an outcrop surface N30°E, 35°SE with lineation pitching 40°NE.

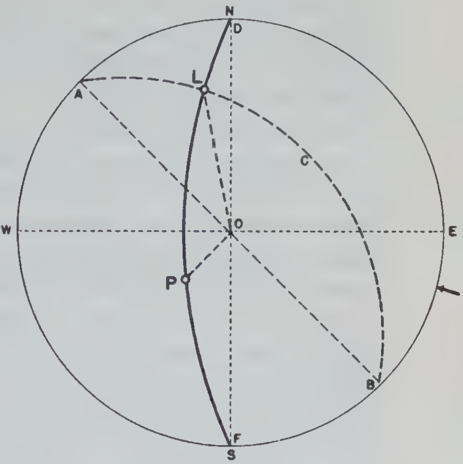

FIG. 3. Construction of the N-plane from data of Fig. 2.

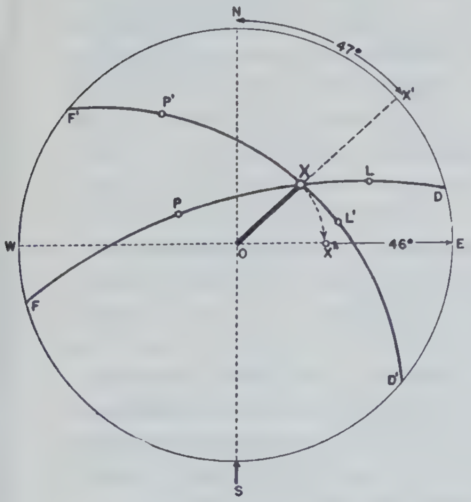

FIG. 4. Graphic solution for the coordinates of linear structure from 2 N-planes.

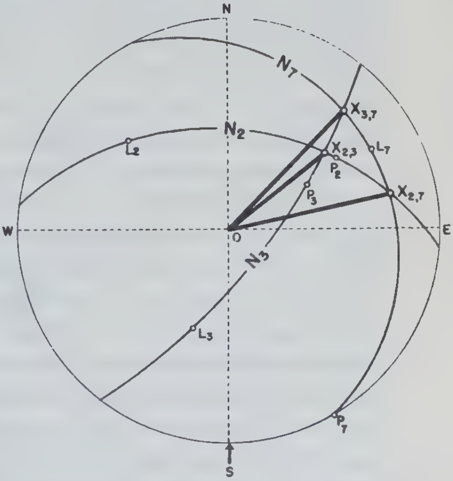

FIG. 5. Multiple graphic solutions for linear structure from 3 N-planes.

Subscripts to N, L, P and X (Fig. 5) refer to numbers of outcrop surfaces used as listed in Table 1.

It is well to remember at the outset that only great circle arcs representing *N*-planes and the projections of their intersections with each other should be drawn on the graphic plot. The dashed lines in the text figures have been added solely for instructive purposes and should not appear on the actual plot.

The illustrative example used in Figs. 2 and 3 involves an outcrop surface striking N30°E and dipping 35°SE. The pitch of lineation in this surface is 40°NE. With the acetate reference markers over the *N* and *S* poles of the net, plot the strike of the surface by placing ticks on the net circumference at N35°E and S35°W (this step is not shown in Fig. 2). Rotate overlay until strike line *AB* coincides with the *NS* net axis (Fig. 2). Plot the dip of 35°SE by counting 35° on the net equator from *E* toward center *O* to obtain point *C*. The great circle arc *ACB* is the projection of the outcrop surface.

The pole *P* of the surface, i.e. the point at which the normal to plane *ACB* pierces the projection hemisphere, is then found by counting 55° or the complement of the dip angle from *W* toward *O*. Finally the projection of the lineation *OL* pitching 40°NE is determined by locating *L*, which lies 40° from *N* along *ACB*. As previously indicated only points *P* and *L* should appear on the acetate overlay at this time.

Now rotate plotting sheet until *P* and *L* come to lie on one of the great circle projections (meridians) of the net and draw in the entire arc between *N* and *S* (Fig. 3). *DLPF* represents the stereographic projection of the *N*-plane which is perpendicular to surface *ACB*, since it contains the plane-normal *OP*, and also includes the trace of lineation *OL*. Repeat this procedure for the remaining outcrop surfaces to obtain the requisite number of *N*-planes.

Figure 4 illustrates the last step of construction. To the *N*-plane *DLPF* of Fig. 3 has been added *N*-plane *D'L'P'F'* derived from a N60°E, 70°SE exposure surface with lineation pitching 42°NE. *X* is the projection pole of the line of intersection *OX* between the two *N*-planes. Assuming ideal cylindrical shape of the linear elements, *OX* then is the trend of linear structure in the rock. To find its coordinates, rotate plotting sheet into the starting position, i.e. with the *N* and *S* reference markers over the corresponding net poles. Extend *OX* to the net circumference and read the bearing $NX' = $ N47°E. Rotate again until *X* lies on the net equator to determine the plunge of linear structure $EX'' = 46°$.

As actual field conditions fall short of the theoretical ideal, the *N*-planes constructed from field measurements will, on the whole, not intersect in a single line, but will give multiple solutions for linear structure coordinates. Figure 5 shows three possible results obtained from three N-planes constructed from field data of outcrop surfaces 2, 3 and 7 of Table 1.

The number of possible graphic solutions increases in arithmetical proportion with the number of exposure surfaces measured and can be expressed mathematically as follows:

$$s=\frac{n(n-1)}{2}$$

whereby s = maximum number of possible graphic solutions
and n = number of N-planes constructed from field data on n outcrop surfaces.

STATISTICAL TREATMENT

The multiple answers obtained from the graphic plot are resolved by finding the statistical median. The two variables involved, namely the bearing of linear structure including the concept of plunge direction and the angle of plunge, are treated separately. It is convenient to express the directional variable (bearing) in terms of 0° to 360° starting at the *S* pole and counting clockwise. Thus 90° indicates a linear structure trending *EW* and plunging *W*, while 270° represents the same bearing with a plunge to the *E*.

Field data from a road cut in Storm King granite at Bear Mountain, New York are listed in Table 1, and are used to illustrate the statistical procedure.

TABLE 1. FIELD MEASUREMENTS FROM ROAD CUT IN STORM KING GRANITE AT BEAR MT., N. Y.

No. of outcrop surface	Strike and dip of outcrop surface	Pitch of lineation
1	N. 50° W., 35° N.E.	81° N.
2	N. 35° W., 62° S.W.	26° N.
3	N. 30° W., 45° S.W.	60° S.
4	N. 5° E., 90°	30° N.
5	N. 15° E., 90°	26° N.
6	N. 30° E., 90°	26° N.
7	N. 60° E., 90°	15° E.

In accordance with the mathematical formula the maximum number of 21 possible answers was realized from the 7 N-planes. Table 2 gives the results of the graphic plot and the statistical solution. Column 1 shows the projection poles of N-plane intersections on the stereogram with subscripts indicating the planes involved. The corresponding coordinates of linear structure are listed in columns 2 and 3. Bearings and plunges thus obtained are arranged in rising numerical order in columns 4 and 5 respectively.

TABLE 2. STATISTICAL TREATMENT OF STEREOGRAM RESULTS

N-plane intersection poles	Coordinates of linear structure from *N*-plane intersections		Coordinates arranged in statistical order		
	Bearing*	Plunge	Bearing*	Plunge	
1	2	3	4	5	
$X_{1,2}$	210°	36°	34°	8°	
$X_{1,3}$	34°	8°	111°	8°	
$X_{1,4}$	211°	28°	205°	9°	
$X_{1,5}$	211°	26°	210°	13°	
$X_{1,6}$	211°	25°	211°	13°	
$X_{1,7}$	212°	13°	211°	14°	
$X_{2,3}$	230°	30°	211°	14°	
$X_{2,4}$	111°	9°	212°	15°	
$X_{2,5}$	269°	8°	218°	15°	
$X_{2,6}$	250°	21°	223°	21°	
$X_{2,7}$	258°	14°	227°	21°	Median
$X_{3,4}$	228°	23°	228°	22°	
$X_{3,5}$	227°	22°	228°	23°	
$X_{3,6}$	228°	25°	230°	25°	
$X_{3,7}$	223°	14°	234°	25°	
$X_{4,5}$	234°	22°	248°	26°	
$X_{4,6}$	218°	26°	250°	26°	
$X_{4,7}$	248°	15°	252°	26°	
$X_{5,6}$	205°	26°	258°	28°	
$X_{5,7}$	252°	15°	269°	30°	
$X_{6,7}$	272°	13°	272°	36°	

* Bearings are given from 0° to 360° clockwise from *S* pole and indicate direction of plunge as well.

The median values of the statistical sequence (columns 4 and 5), then, give a bearing of 227° or N47°E and a plunge of 21°NE for the average linear structure in this road cut.

To test the accuracy of this method, certain additional field information pertaining to the above outcrop has been withheld from the reader. Lineation on a horizontal exposure surface had an average strike of

N45°E which is equivalent to the bearing of the linear structure. Adding the *N*-plane constructed from this horizontal surface to the graphic plot, 7 more possible sets of coordinates are found making a total of 28. The resulting median of N45°E, 22° shows but a minor refinement of the values obtained without field data from a horizontal surface.

Furthermore no visible mineral elongation was observed on a N70°W, 52°SW exposure, even though this surface evidently does not cut the linear structure of the rock exactly at right angles. The answer is to be found in the fact that the cross-sections of the linear hornblende elements are approximately, but not truly equi-dimensional. In this case, an exposure oriented exactly perpendicular to the axes of the linear elements would actually show crude but distinct parallelism in the direction of the crystallographic *b* axis. Generally speaking, therefore, coordinates of linear structure can be determined only in the crudest fashion from the orientation of outcrop surfaces showing a lack of visible lineation.

The solution of this problem by the use of the statistical median also has the advantage of minimizing the effects of certain inaccurate field measurements due to inadequate size of outcrop surface, indistinct lineation or sudden local variations of structure. Obviously impossible results will automatically appear at the extreme ends of the statistical column where they will have little influence on the median. Experience has shown that 7 to 8 adequate exposure surfaces give optimum statistical results, taking into account all factors including time involved in performing the necessary operations.

Conclusion

The coordinates of linear structure can be determined with reasonable accuracy from field data obtained from 6 to 8 different outcrop surfaces by the use of the stereographic projection followed by simple statistical treatment of the graphic results. This method is limited to rocks which do not show any visible platy flow structure or foliation, and whose linear elements are minerals with roughly equi-dimensional cross-section, such as quartz, hornblende, augite, etc. It is particularly useful when the bearing of the linear structure is not known owing to the lack of data from a horizontal exposure surface. The coordinate values represent the average for the entire outcrop.

This method has been applied by the writer with good results to numerous road cut exposures of the Storm King granite in the Hudson Highlands of New York. It is readily adaptable to field use, since little equipment is necessary and the time factor is not prohibitive.

In conjunction with petrofabric analysis of the Storm King granite this procedure was also used for finding the preferred dimensional orientation of quartz grains lacking similar space lattice arrangement from oriented thin sections. The pitch of preferred quartz elongation in these sections of various known orientations was determined by azimuth counts (Haff, 1938, p. 571).

ACKNOWLEDGMENT

Helpful suggestions by Eugene S. Simpson, graduate student in the Department of Geology, Columbia University are gratefully acknowledged.

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KAOLINITE AFTER BERYL FROM ALTO DO GIZ, BRAZIL

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Abstract

A large pseudomorph of kaolinite after a cesium-bearing beryl from Alto do Giz, Brazil, is described. The beryl has been replaced to the extent of about 28.3 per cent kaolinite by weight. Although weathering appears to have been a dominant alteration feature of the deposit there is reason to believe that the pseudomorph could have been produced by hydrothermal action.

Introduction

On a recent trip to Brazil, Dr. Frederick H. Pough of The American Museum of Natural History collected an unusual pseudomorph of kaolinite after beryl from Alto do Giz, Rio Grande do Norte. Before removing samples for study and analysis, the crystal measured over six inches in length and nearly four inches across. The pseudomorph shown in Fig. 1, has the form of a typical beryl crystal consisting of the hexagonal prism and pinacoid. It is yellowish to dull white in color and superficially appears to have been largely, but not completely, kaolinized. The color of the prism faces and the two ends in contrast to the interior suggests that kaolinization in the outer portion has been more complete than on the inside.

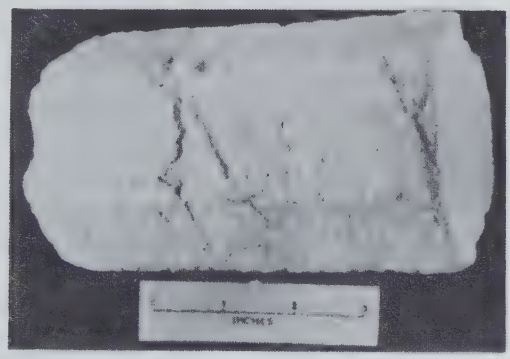

Fig. 1. Pseudomorph of kaolinite after beryl, Alto do Giz, Brazil.

It was decided that the information to be gained warranted the removal and destruction of a considerable portion of the crystal for study. Hence, one end of the specimen was sacrificed in order to provide samples for chemical analysis, chips for thin sections, and material for optical and x-ray examinations.

NATURE OF THE REPLACEMENT

In determining the extent of replacement a sample weighing 225 grams was allowed to disintegrate in water. The clay was washed out, decanted, and allowed to settle in large beakers, about 2.67 per cent of material being unrecovered. The residue of beryl was collected after being washed free from clay. The amount of clay collected was 28.3 per cent of the total residue by weight, while the beryl amounted to 71.7 per cent.

The minerals in the pseudomorph are chiefly beryl, and kaolinite. Muscovite is present in small amounts and occasional grains of quartz may be observed under the microscope. There are small amounts of limonitic stain. Identifications of the beryl and kaolinite have been confirmed by *x*-ray diffraction (Fig. 2) and optical examination.

No evidence of kaolin minerals other than kaolinite could be observed even in photographs with the electron microscope (Fig. 3). At a magnification of 16,000 diameters irregular plates and groups of plates may be observed with occasional individuals showing a pseudohexagonal outline characteristic of kaolinite. Elongate forms suggesting halloysite did not appear in the photographs available. The photograph reproduced in Fig. 3 at a magnification of 8000 diameters was furnished through the courtesy of the Palmerton Research Laboratory of the New Jersey Zinc Co.

Several thin sections distributed through the crystal in different positions and orientation were cut from the pseudomorph. These included sections cut normal to the *c*-axis from the central core and from the outer zone, as well as sections cut parallel to prism faces.

In all sections beryl could be observed in various stages of replacement. Beryl in basal thin sections yields uniaxial negative interference figures, notwithstanding the division of the beryl into isolated portions by kaolinite. The beryl in sections cut parallel to the prism yields maximum birefringence. It is assumed that the original crystal was either an individual unit of beryl or was made up of closely parallel crystals.

Although the beryl pseudomorph was found in a pegmatite at Alto do Giz, no evidence of feldspar either in residual fragments or relict forms could be observed in thin sections. Infiltration of the kaolinite through the beryl appears to have taken place by direct replacement first along incipient fractures, later followed by mass invasion.

The penetration of the solutions responsible for the replacement of the beryl by kaolinite appears to have been aided materially by the widespread distribution of microscopic cavities throughout the beryl. These are observable in thin section and vary in sectional pattern with orienta-

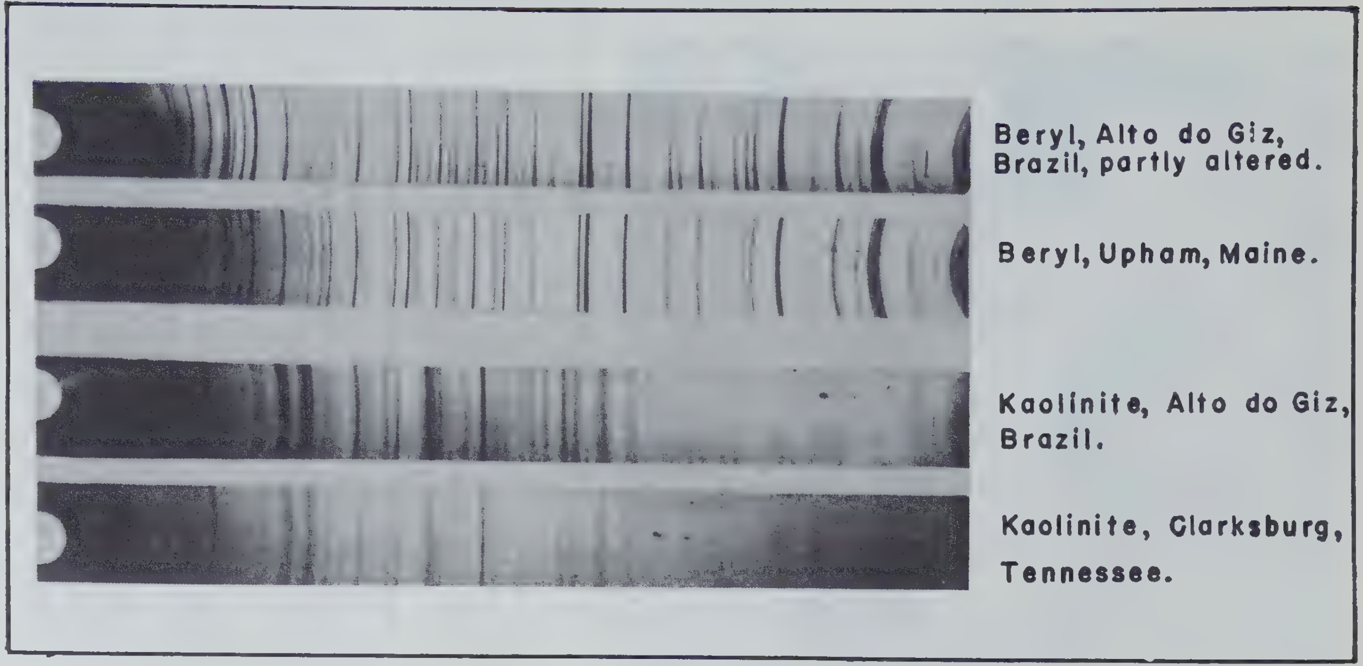
Beryl, Alto do Giz, Brazil, partly altered.
Beryl, Upham, Maine.
Kaolinite, Alto do Giz, Brazil.
Kaolinite, Clarksburg, Tennessee.

FIG. 2. Comparison of x-ray diffraction patterns of beryl and kaolinite with reference patterns.

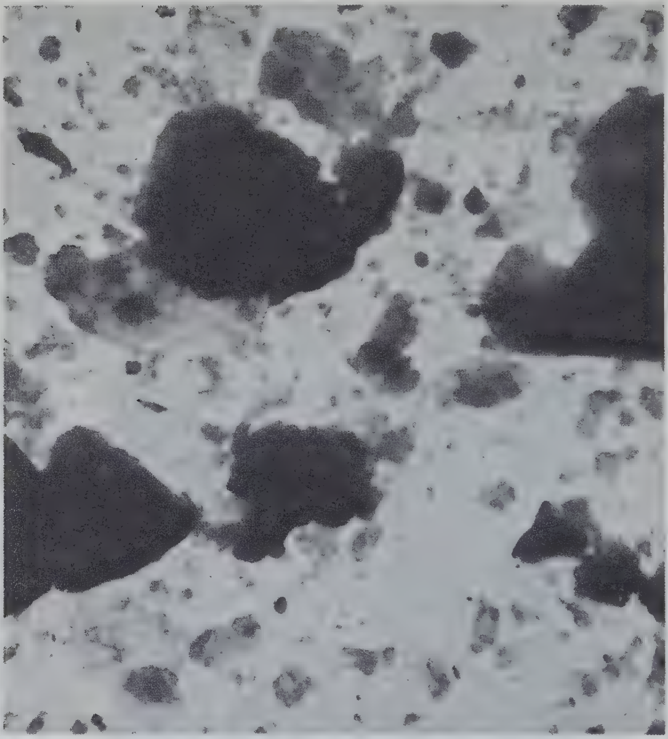

FIG. 3. Electron micrograph of kaolinite from Alto do Giz, Brazil. Magnification 8,000×.

tion. In basal sections the cavities frequently exhibit hexagonal outlines varying from about 5 to 40 microns across. The hexagonal cavities may be interspersed with round or irregular cavities devoid of symmetry. In vertical sections patterns are not hexagonal, but assume elongate shapes frequently suggesting the cross section of a flat hexagonal cavity. Such sections may be about 2 or 3 microns thick and as much as 40 microns in length. In places, these cavities are enlarged into angular shapes resembling the cross sections of pyramidal protuberances. Some are round or irregular.

No evidence of fluids could be observed in the cavities. On the other hand, incipient alteration to kaolinite is common. Cavities in various stages of alteration by kaolinite may be seen, from the first stages in which a few small kaolinite specks line the walls of a cavity, to completely kaolinized cavities or relict outlines of cavities dispersed through areas of kaolinite. Apparently the cavities provide points of weakness where kaolinization has progressed more rapidly than in solid areas.

CHEMICAL ANALYSES

Chemical analyses of both altered and unaltered beryl and kaolinite from Alto do Giz have been made (Table 1). The original beryl (analysis no. 2) represents a clear transparent crystal which is free from alteration aside from a few scattered inclusions of mica distributed along the walls of cavities. The material selected for analysis was free from these inclusions. The Brazilian crystal agrees reasonably well with an analysis of cesium beryl from Hebron, Maine, by H. L. Wells, reported by Dana (1892, p. 407, no. 10). The two are shown for comparison in Table 1.

TABLE 1. ANALYSES OF BERYL AND ALTERATION

	Hebron, Maine	Alto do Giz, Brazil* Original Beryl	Intermediate stages*—		Kaolinized Residue*
	(1)	(2)	(3)†	(4)†	(5)
SiO_2	62.44	62.90	58.55	54.97	44.98
Al_2O_3	17.74	18.88	25.51	28.03	36.84
Fe_2O_3	0.40	.18	.90	2.86	2.09
FeO		.00	.05		.10
MgO		.00	.15	.15	.11
CaO		.00	.01	.01	.00
Na_2O	1.13	1.01	.28	.28	.24
K_2O		.40	.42	.42	.65
H_2O+	2.03	2.15	5.44	(8.42)‡	13.53
H_2O-		.03	.31		.78
TiO_2		.02	.13		.20
P_2O_5		.02	.09	.09	.17
Li_2O	1.60	1.00	.05		.05
Cs_2O	3.60	2.18	.05		.08
BeO	11.36	11.00	8.01	4.54	.24
	100.30	99.77	99.95	99.77	100.06

* Analyses by Dr. Lee C. Peck, Rock Analysis Laboratory, University of Minnesota.

† Sample No. 3 was used for the minor constituents of No. 4 (MgO, CaO, Na_2O, K_2O and P_2O_5). Sample No. 3 was supplied as a duplicate of No. 4 but proved to represent a less advanced stage of alteration.

‡ Loss on ignition.

Analyses numbered 3 and 4 represent partially replaced beryl from the Alto do Giz pseudomorph. The residue from repeated washing to remove the kaolinite was submitted for analysis. The analyses exhibit significant decreases in SiO_2, Na_2O Li_2O, Cs_2O, and BeO with correspondingly significant increases in Al_2O_3, Fe_2O_3, H_2O and TiO_2.

The kaolinite fraction separated from the beryl remaining in the pseudomorph has been analyzed as shown in number 5. The analysis of the kaolinite residue, Table 2, has been recast to eliminate beryl, potash and soda micas, and limonite. Aside from a small excess of Al_2O_3 and H_2O the remainder agrees reasonably well with the analysis for normal kaolinite. The TiO_2, H_2O and P_2O_5 were unassigned in the recast. Since the amounts due to these constitutents are small their elimination only slightly affects the total.

TABLE 2

	Kaolinite Residue	Beryl	Micas		Limonite	Remainder	Kaolinite Analysis	Kaolinite Theoretical $Al_2O_3:SiO_2=1:2$
			Potash	Soda				
SiO_2	44.98	1.15	2.49	1.40		39.94	*46.48*	46.5
Al_2O_3	36.84	0.33	2.12	1.19		33.20	*38.64*	39.5
Fe_2O_3	2.08				2.08			
FeO	0.10							
MgO	0.11							
CaO	0.00							
Na_2O	0.24			0.24				
K_2O	0.65		0.65					
H_2O+	13.53		0.25	0.14	0.35	12.79	*14.88*	14.0
H_2O-	0.78							
TiO_2	0.20							
P_2O_5	0.17							
Li_2O	0.05							
Cs_2O	0.08							
BeO	0.24	0.24						
	100.05	1.72	5.51	2.97	2.43	85.93	100.00	100.00

The analyses offer no indication of concentration of either cesium or beryllium in the kaolinite fraction. The kaolinite contains little beryllium and cesium and is apparently in no way unusual in composition. It would appear that the solution which removed portions of the beryl crystal to make room for the deposition of kaolinite carried away the two elements in question. There appears to be no evidence from the study of the pseudomorph to indicate the final site of deposition of the dissolved cesium and beryllium.

OPTICAL PROPERTIES

The indices of refraction for the unaltered beryl of analysis number 1 are $n_\omega = 1.590$; $n_\epsilon = 1.581 \pm .001$. The indices of refraction of beryl from the central core of the pseudomorph are $n_\omega = 1.576$; $n_\epsilon = 1.568 \pm .001$. Although the difference between the two sets of values is perceptible, both values lie within the normal range for beryl. Although the altered material has lower indices of refraction insufficient data are available to attach much significance to this fact.

The indices of refraction of the kaolinite are higher than kaolinite reported from other localities, having the values $n_\gamma = 1.577$; $n_\alpha = 1.571 \pm .002$, but the Debye type x-ray diffraction pattern agrees with similar patterns of other samples of kaolinite available for comparison.

ALTERATION PROBLEM

The conditions under which alteration occurred are not clearly indicated. The locality has been described by Pough (1945). Kaolinization of feldspar is reported to be a prominent feature of the pegmatite in which the beryl pseudomorph was found. This has been attributed to weathering (Pough, p. 507). Although the possibility exists that the alteration is not the result of weathering, nothing was observed in the pegmatite other than the depth of alteration, to indicate that hydrothermal activity caused the kaolinization.

Clean cut cavities and microscopic inclusions were observed in a clear transparent beryl crystal from the same locality. Cavities, in the case of a resistant silicate such as beryl, would seem to indicate a form of thermal solution. One would expect weathering to affect the surface of the crystal and would be more of a surficial phenomenon. On the other hand, it is not clear whether the kaolinization accompanied the thermal solution or represented later activity. Johnson (1945, p. 1024) points out that pegmatites in the northeastern Brazilian area which lie on an old peneplain have little or no topographic expression and in many of them the feldspars have weathered to kaolin. Since the cavities are unfilled except by kaolinite it is reasonable to relate the introduction of the kaolinite to the etching phase. Under such circumstances, the kaolinite could have been hydrothermal in origin. Unfortunately, more information on this interesting feature does not appear to be available.

Acknowledgments

The writer wishes to thank Dr. Frederick H. Pough and The American Museum of Natural History for furnishing the material upon which this description has been based. He is also grateful to Dr. Lee C. Peck of the Rock Analysis Laboratory of the University of Minnesota for his cooperation in connection with the chemical analyses. The support of the Administration of Columbia University in furnishing funds for research is also gratefully acknowledged.

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INFLUENCE OF TWINNING ON THE USABILITY OF QUARTZ FROM VARIOUS LOCALITIES

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Abstract

In the execution of a development contract for the Long Branch Signal Laboratory over 3,000 quartz crystals from sixteen localities were studied. The purpose of the study was to determine, if possible, which localities yielded the best quartz for the manufacture of oscillator plates. The determination of the percentages of Dauphiné and Brazil twinning constituted the main part of the problem. Considerable variation in amount of twinning was found from one locality to another. Crystal habit can be correlated in a general way with the percentage of Dauphiné twinning. The presence of minor elements, determined spectrographically, appears to be unrelated to other observed properties.

Introduction

During the war years of 1942 to 1945 quartz crystals of high quality were in tremendous demand for manufacture into oscillator plates for the control of radio frequencies. The phenomenal rise of this industry and methods used to convert laboratory techniques into industrial processes are described in a symposium in the May-June 1945 issue of The American Mineralogist.

Of the several Government agencies procuring crystal oscillators, the Signal Corps obtained by far the largest quantity and was thus vitally interested in perfecting high quality oscillators at lower cost. To this end the Long Branch Signal Laboratory† devoted its efforts. The data presented in this paper were obtained in the carrying out of a development contract for the Signal Laboratory by the Cambridge Thermionic Corporation of Cambridge, Massachusetts. It was the writer's privilege to direct the work and correlate the results.

The effort to locate and develop domestic sources of quartz crystals was unsuccessful and thus all but minor amounts were imported, mostly from Brazil.

Because of the method by which quartz is mined, collected, graded and sold, any given shipment reaching the United States is a fairly good cross-section of Brazilian quartz. That is, it contains crystals of comparable size and quality, but from many different and unknown localities. Since it is impossible to determine the presence or absence of Dauphiné twinning by usual inspection methods, it plays no part in the normal quality grading. Might it not be true that quartz from one Brazilian locality is of superior quality while that from another is decided inferior from the point of view of Dauphiné twinning?

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* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 279.

† Now Frequency Control Branch of the Squier Signal Laboratory.

If a careful study could be made of quartz taken from different localities, it might show each lot to have a group of properties peculiar to itself. These properties considered collectively might show quartz from one locality to be much more desirable than that from another for the manufacture of quartz oscillator plates. If mining development work is to be done in the future, the report of characteristics of quartz from various localities would serve as a sound basis for predicting which locality would give the greatest return for money and effort expended.

Of the several individuals in the Signal Corps interested in such a study of quartz, Lt. Colonel Allyn C. Swinnerton, Captain Joseph S. Lukesh and Dr. Richard E. Stoiber were most instrumental in initiating the program. Minerals Division of Foreign Economic Administration was likewise highly interested in the determination of quartz characteristics as related to locality. In this agency Dr. Carl Tolman in Washington and Dr. Robert D. Butler in Brazil arranged for the collection and identification of specimens and for the special handling required.

The securing of various lots of quartz from known localities and transporting them to the United States presented many difficulties of considerable magnitude. That portion of the problem which was taken care of by FEA, as well as the geologic nature of the deposits, is beyond the scope of this report and is not touched upon.

PROCEDURE

Altogether 3015 quartz crystals weighing 2157 pounds were studied. They came from 16 localities, 13 of which were in Brazil, 2 in Guatemala, and 1 in Columbia, as listed in Table 1.

It should be pointed out that lots were representative of the localities and no effort was made to grade them. Indeed, it was only with considerable difficult that the Foreign Economic Administration was able to collect and ship these sample lots to the United States and at the same time preserve their identity. Thus in a given lot were crystals of all sizes, some high quality, some low quality if such were representative.

Each crystal on arrival was inspected visually and a record made of crystal forms and habit, flaws, ghosts and any unusual features. Before cutting, each lot was photographed; a typical sample lot is shown in Fig. 1. Wafers suitable for oscillators, about .050″ thick were then cut from the crystals and etched in ammonium bifluoride to make twinning visible,

TABLE 1. QUARTZ STUDIED*

Lot No.	No. of Crystals	Weight in Pounds
1	200	116.05
2	200	123.86
3	200	116.27
4	200	115.72
5	199	132.55
6	200	144.10
7	170	109.01
8	146	226.93
9	350	185.35
10	135	197.11
11	173	109.23
12	166	86.79
13	200	123.09
14	175	110.81
15	195	165.20
16	106	94.83
	3015	2156.90

* Lots 1 to 13 are from Brazil, lot 14 from Colombia, and lots 15 and 16 from Guatemala. The names of specific localities are withheld for security reasons.

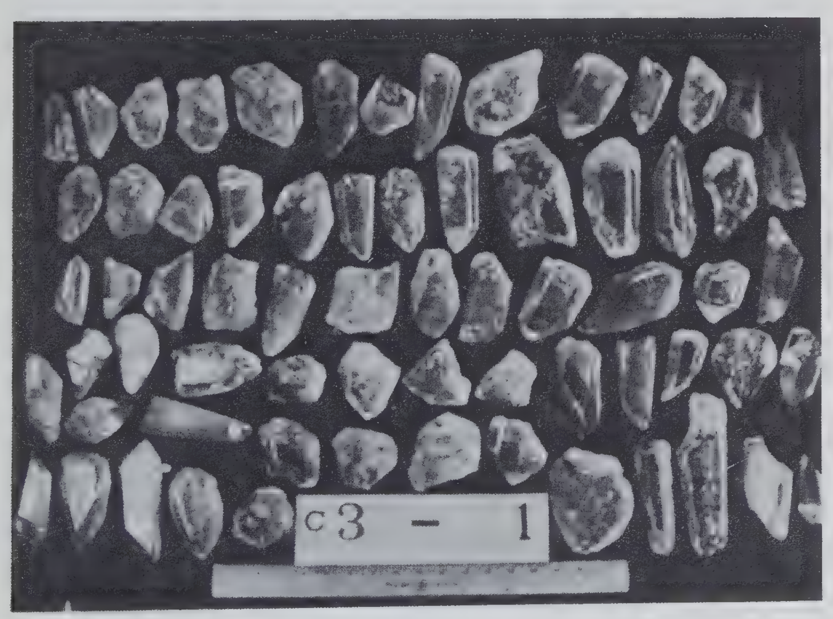

FIG. 1. Typical sample lot of quartz.

Those portions of the wafers that were in twinned position to the main part were marked out with pencil as shown in Fig. 2. Although emphasis was laid on determining the percentage of Dauphiné (electrical) twinning, since etching is the only way to render it visible, Brazil (optical) twinning was also marked out and recorded. The determination of the volume percentages of these two types of twinning in the lots from the various localities was the chief purpose of the investigation. It also proved to be the most time-consuming part, for over 52,000 slices were examined individually. After trying several methods that proved impractical, the following procedure was used to obtain the volume percentage of both types of twinning in each crystal.

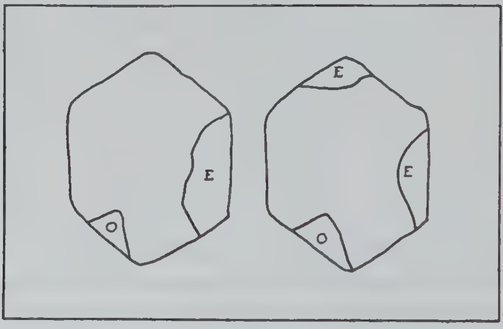

Fig. 2. Twinning marked out in quartz wafers. *E* is Dauphiné twinning; *O* Brazil twinning.

After being marked for twinning, the slices were inserted in a photographic enlarger in the position where one would normally place the film. The images of the slices, magnified to three times the area, were projected on white paper and a tracing made. Figure 2 is such a tracing reduced to one-sixth, or to one-half the size of the slices themselves. After all the slices from a given crystal had been thus outlined, the tracings were cut out with scissors and separated into three groups: 1. That representing the good portion of the slice, 2. That representing Dauphiné twinning, 3. That representing the portion rendered useless by Brazil twinning. Each of the above groups was then weighed separately on a chemical balance; and, making the assumption that a given sheet of paper was of uniform thickness and weight, the percentages of Dauphiné and Brazil twinning were then determined for the whole crystal.

The above method was checked against a similar one using a polar planimeter to determine the areas of the projected slices. The two methods showed a remarkably close agreement and it is probable that the percentages of twinning are accurate to within one or two per cent of the markings on the slices. Additional error is obviously involved in the original marking out of the twinning, but it is believed that that is no more than two or three per cent; thus making the accumulative error not greater than five per cent.

The number of oscillator plates that could be obtained from a pound of quartz from a given locality was of as much interest to the Signal Corps as the percentage of twinning. One might expect a direct relation of the two but other things such as flaws, shape and distribution of twinning enter in as complicating factors. Thus a record was kept of blanks cut from each crystal. A "blank" as spoken of here is an oriented rectangular portion of a slice that will yield a finished oscillator 0.5×0.6 inches. From the manufacturer's point of view the best quartz is that yielding the most blanks per pound or rather per dollar. In general, the larger the crystal the more blanks per pound but not necessarily per dollar, for the cost per pound rises rapidly in the larger sizes.

The handling of large quantities of quartz crystals from known localities presented a unique opportunity to obtain data of interest even though they were not pertinent to the main problem. Consequently, blanks were selected from each lot of quartz and finished to a frequency of 7640 KC. Two of these finished oscillators from each lot of quartz were then exposed to x-ray irradiation, after the method described by Frondel,* to determine the maximum change in frequency. After irradiation one of the two oscillators was powdered and subjected to spectrographic analysis to determine the presence of minor elements.

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* Clifford, Frondel, Final frequency adjustment of quartz oscillator-plates: *Am. Mineral.*, 30, 427–431 (1945).

Data Obtained

In Table 2 the grading of the National Bureau of Standards for each lot is listed together with the percentages in each size group. Table 3 summarizes the data obtained on twinning, and the yield of blanks per pound. It is believed that the method of cutting gave the highest possible yield. It should be pointed out, however, that there are several methods of sectioning quartz and that another manufacturer using a different method might have obtained fewer blanks from the same quartz.

Table 2. Grades and Sizes of Quartz

Lot No.	Wt. % of Faced Quartz	National Bureau of Standards Grades in Weight Per Cent					Size of Crystals in Per Cent		
		1	2	3	BG	S8	100–200 g.	200–300 g.	300–500 g. & over
1	100.0		31.8	38.4	15.7	14.1	29.1	2.3	68.6
2	100.0	2.1	51.7	15.3	10.0	20.9	30.0		70.0
3	100.0	2.1	51.6	13.1	21.5	11.7	30.6		69.4
4	100.0	2.9	48.3	4.9	38.0	5.9	29.5		70.5
5	72.3	11.1	74.5	14.0	.4			39.6	60.4
6	46.7	4.8	72.2	18.5	4.5			41.1	58.9
7	35.5	41.2	44.0	12.2	2.6			52.4	47.6
8	17.4	1.2	92.0	6.8				4.3	21.7
									3– 500 g.
									74.0
									500–4000 g.
9	94.9		49.7	11.6	15.5	23.2	37.3		62.7
10	93.1		81.0	18.2	.8			10.6	89.4
									300–5000 g.
11	100.0	1.7	61.4	12.5	9.4	15.0	22.5	.5	77.0
12	100.0	3.3	53.3	8.2	20.7	14.5	34.0	66.0	14.8
13	100.0		70.2	3.4	16.4	10.0	26.2		73.8
14	100.0	23.7	43.7	10.9	12.8	8.9	8.9	40.2	50.9
									300–2000 g.
15	54.7		4.1	95.9				28.9	71.1
									300–2000 g.
16	51.3	5.5	81.8	10.7		2.0	2.0	27.5	75.5
									300–3000 g.

In Table 3 can be found the answer to the main question, namely; Is quartz from one locality better than that from another for the manufacture of oscillator plates? Neglecting the Guatemala and Columbian quartz* (Lots 14–16), which proved to be definitely inferior, the yield of blanks per pound ranged from 57 to 85. One can see at a glance that there is far from a perfect correlation between percentage of twinning and blanks per pound. Such a condition might well be expected since locality is only one of several variables involved. The other major variables are:

Table 3. Analyses of Slices

Lot No.	Volume % Not Twinned	Volume % Twinning		No. of Blanks per Pound	Scrap Wt. %
		Dauphiné	Brazil		
1	78.41	20.07	1.52	69.9	9.34
2	86.72	11.91	1.37	85.2	10.31
3	79.58	16.59	3.83	68.7	9.86
4	90.70	8.27	1.03	74.1	8.26
5	84.99	12.90	2.11	76.9	11.41
6	85.94	6.62	7.44	57.4	18.46
7	84.07	12.07	3.86	57.3	16.57
8	90.57	9.24	.19	56.8	22.34
9	85.40	8.56	6.04	66.9	12.54
10	80.03	9.24	10.73	63.0	9.51
11	85.28	3.43	11.29	63.7	11.27
12	89.60	2.91	7.49	65.7	14.84
13	91.19	4.79	4.02	68.9	13.20
14	70.88	8.53	20.59	47.3	13.37
15	15.31	84.41	.28	6.8	11.50
16	75.11	21.45	3.44	49.2	16.61

1. Proportion of faced and unfaced quartz
2. Grade
3. Size
4. Distribution of twinned area

1. *Proportion of faced and unfaced quartz.* In cutting faced quartz, the crystals were mounted on natural faces and no preliminary cuts were made. Unfaced quartz required that a face be sawn parallel or nearly parallel to $\{11\bar{2}0\}$ on which to mount it and a face be cut parallel to $\{0001\}$ for orientation purposes. The amount of scrap from unfaced quartz was thus large, reducing proportionally the amount to be cut into wafers.

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* It would be unfair from this study to make the generalization that all quartz from Guatemala and Columbia is low grade, since such limited quantities were available.

2. *Grade.* Since each lot of quartz was a representative sample of the locality from which it came, several grades were present in each. The amount of quartz of each grade in the various lots had been determined both in Brazil and at the National Bureau of Standards in Washington. The grade was based on the estimated usable percentage from the point of view of flaws, inclusions and Brazil twinning. In Table 1 the area of of the slices listed as "not twinned" means that it is usable as far as twinning is concerned. It does not mean that it is free from flaws and imperfections that might render it useless for cutting a blank. When blanks were marked out on the slices, the flaws were avoided as well as the twinning; and thus a badly flawed crystal even with very little twinning would show a low yield of blanks.

3. *Size.* The crystals in all lots showed a considerable range in size, and an even greater range from one lot to another. The weight of individual crystals varied from 100 grams to over 4000 grams. For a fair comparison of one lot with another, only those crystals of comparable size should be considered, for, other things being equal, it appears that the 300- to 500-gram quartz has the best yield of blanks per pound.

4. *Distribution of twinning.* The areal distribution of twinning in a given slice has almost as great an effect on the number of blanks obtained as the percentage of twinning. Isolated patches of Dauphiné twinning or long slender spines of Brazil twinning may render the slice useless even though the total area of twinned portion may be only a few per cent.

Comparison of Lots

It is interesting to note the effects of the differences in the four variables mentioned above in comparing one lot with another. Although it is difficult to specify how one variable affects the results, or how much one offsets or supplements another, still some lots in comparison show definite reasons for the results obtained.

For example, compare Lots 2 and 4. Both are 100 per cent faced and roughly the same as to size; the only major difference lies in the grade, with Lot 2 having a considerably better average. Even though Lot 4 has less twinning, the yield of blanks per pound for Lot 4 is 74.1 against 85.2 for Lot 2. The best explanation seems to lie in the grade difference (although the areal distribution of twinning in the slices may have influenced the results), and one can conclude the locality of Lot 2 yields a somewhat higher grade of quartz than the locality of Lot 4.

Again, comparing Lot 5 with Lot 6, the former has 25.6 per cent more faced quartz and also an advantage of 6.3 per cent of grade 1. The sizes and other grades are roughly comparable. Both lots have about the same percentage of twinning, yet Lot 5 yielded 19.5 more blanks per pound. This large difference may be in the fact that Lot 6 is only 46.7 per cent faced as against 72.3 per cent for Lot 5. This would also account for the difference in scrap, 18.46 per cent for Lot 6, 11.41 per cent for Lot 5. Similar results in blanks per pound and in per cent scrap are noted for all lots with low percentages of faced quartz, even when the percentage of twinning is low.

Compare Lot 6 and Lot 7. Lot 6 has 11.2 per cent more faced qaurtz and 11.3 per cent more in 300–500 gram size. Against these advantages is a disadvantage of 36.4 per cent in Grade 1. The percentages of twinning are comparable. Blanks per pound in the two lots are the same, and it appears that here the variables offset each other almost exactly.

Likewise a comparison of Lots 1 and 3 shows a similar yield of blanks. Both are 100 per cent faced and the sizes and percentage of twinning are comparable. The variation in the grades of the two lots is the only major difference and these equalize one another to make quartz from both localities equally desirable.

Each lot of quartz as received was packed in several boxes and each box was handled separately. Two boxes in Lot 2 and one in each of Lots 4 and 5 gave approximately 90 blanks per pound, the highest yield. In each of these the quartz was 300–500 gram. In none of the boxes containing smaller or larger quartz did the number of blanks approach this figure.

Effect of Habit on Twinning

In the initial inspection of the quartz a record was made of the habit. Crystals were divided into two groups: one "candle" quartz, long relatively slender crystals with tapering prism faces; and, two, "equidimensional," in which the dimension along the *c*-axis was roughly equal to the dimension along the *a*-axis, and the prism faces were not markedly tapered. Obviously, unfaced quartz could not be classed in either group. It appeared as work progressed that in general the "candle" quartz was superior to the equidimensional types of similar weight and an analysis of the final data was made to determine whether or not this was a valid conclusion.

This seemed particularly true of Lots 1–4, which were 100 per cent faced and records were available on the eleven individual boxes that comprised them. In Fig. 3 the percentage of Dauphiné twinning is plotted against the percentage of "candle" quartz. There is far from a regular distribution of points, but there is a trend showing that the higher percentage of "candle" quartz, the lesser the amount of Dauphiné twinning.

Among those who have examined large quantities of quartz crystals, it is common knowledge that Brazil twinning tends to be located near the borders of the crystals. It is usually observed on etched slices as triangular-shaped areas with the base of the triangle at the edge and with the apex pointing toward the center. The sides of the triangle are parallel to the *a*-crystallographic axes. Therefore, the percentage of Brazil twinning in unfaced quartz is usually low because much of it has been broken off. Thus in Lot 9 with only 17.4 per cent faced quartz, Brazil twinning amounted to only 0.19 per cent. In order to have a comparison of the two types of twinning significant from the crystallographic point of view, only faced quartz should be considered.

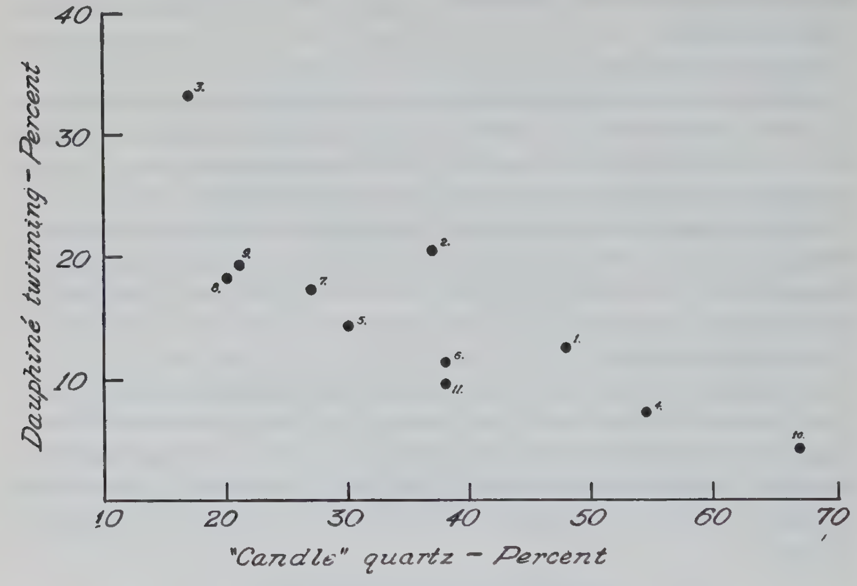

FIG. 3. Relation of "candle" quartz to Dauphiné twinning.

Eight of the lots (1, 2, 3, 4, 11, 12, 13 14) studied contained only faced quartz and these were made up of 26 individual boxes on which records were kept separately. Of these, 9 had less than 2 per cent Brazil twinning, but with Dauphiné twinning making up as much as 33 per cent. In the remaining 16 boxes, Brazil twinning varied up to 38 per cent and only in one of them did Dauphiné twinning amount to more than 9 per cent. Since the weight of quartz varied considerably in the different boxes, the amount of twinning in terms of pounds was calculated and is listed in the tables below.

TABLE 4. BOXES IN WHICH BRAZIL TWINNING WAS LESS THAN 2 PER CENT

Lot No.	Box No.	Dauphiné Twinning Pounds	Brazil Twinning		Total Weight Pounds
			Pounds	Volume %	
1	2	8.40	.43	1.04	41.0
1	3	13.60	.33	0.80	41.0
2	2	8.20	.30	0.50	59.9
2	3	3.58	.63	1.84	34.2
3	1	6.09	.22	0.62	35.8
3	2	6.15	.43	1.08	39.4
4	1	1.46	.44	1.28	34.2
4	2	1.89	.24	0.87	27.5
4	3	6.18	.51	0.95	54.0
		55.55	3.53		367.0
		15.14%	0.96%	Total twinning 16.10%	

TABLE 5. BOXES IN WHICH BRAZIL TWINNING WAS GREATER THAN 2 PER CENT

Lot No.	Box No.	Dauphiné Twinning Pounds	Brazil Twinning		Total Weight Pounds
			Pounds	Volume %	
1	1	4.11	1.04	3.06	33.9
2	1	3.52	.85	2.24	37.7
3	3	7.04	3.66	8.92	41.1
11	1	2.52	5.37	9.64	55.8
11	2	1.19	6.92	12.96	53.5
12	1	1.12	2.44	8.15	30.0
12	2	1.42	4.06	7.15	56.8
13	1	2.04	2.89	5.19	55.8
13	2	3.12	1.53	2.87	54.5
14	1	.30	.43	10.27	4.2
14	2	.30	.63	11.01	5.7
14	3	2.01	4.75	21.32	22.3
14	4	2.43	3.06	14.57	21.8
14	5	6.05	5.50	24.46	22.5
14	6	1.84	2.96	17.40	17.0
14	7	.60	3.41	27.76	12.3
14	8	.15	1.93	38.58	5.0
		39.76	51.43		529.9
		7.50%	9.71%	Total twinning 17.21%	

The figures in the above tables show that when Brazil twinning is present in only small amounts, Dauphiné twinning is abundant; and, conversely, when the percentage of Brazil twinning is greater, Dauphiné twinning is less. In several cases it appears that not only does Dauphiné twinning decrease with increase of Brazil twinning but the total percentage of twinning is less.

Right Hand vs. Left Hand

With the exception of the first three lots studied the hand of the quartz was observed and is recorded in Table 6. Of the 2414 crystals, 1224 or 50.7 per cent were left hand and 1191 or 49.3 per cent were right hand. This is what would result from a purely statistical basis if it were a matter of chance whether a quartz crystal were to be right- or left-hand. It appears obvious, therefore, that locality has no influence on this property.

An attempt to correlate the hand of the quartz with other observed data showed that it has no apparent relation to twinning either in amount or kind and is quite independent of habit.

Table 6. Number of Right- and Left-Hand Crystals

Lot No.	Hand		Lot No.	Hand	
	Left	Right		Left	Right
4	97	103	11	83	90
5	109	90	12	83	83
6	100	100	13	97	103
7	79	91	14	88	87
8	72	74	15	84	111
9	196	154	16	62	44
10	74	61	Total	1224	1191

Spectrographic Analyses and X-ray Irradiation

Two crystals were selected at random from each lot of quartz and from each of them two oscillator plates were finished to a frequency of 7640 KC. These plates were then exposed to an intense x-ray beam in an irradiation unit built by North American Philips Company for that purpose. Such exposure lowers the frequency and tends to make the quartz smoky. The change of frequency was recorded for each oscillator plate, but it seems unnecessary to list all the data here, for no apparent correlation existed between change in frequency and the other observed properties. It is impossible to draw definite conclusions regarding the effect of x-ray irradiation of quartz from different localities, but from the limited data available it appears that there may be a correlation. Certain lots of quartz were nearly all smoky and the oscillators from these, as one would expect, changed frequency but little on exposure.

After exposure to *x*-ray irradiation, two of the oscillators from each lot were selected and analyzed spectrographically* for the presence of minor elements. The results of these analyses are given in Table 7 with the change in frequency induced by *x*-ray irradiation in that particular plate of quartz. The presence of the minor elements seems to have no influence on the change in frequency.

TABLE 7. SPECTROGRAPHIC ANALYSES OF OSCILLATOR PLATES

Lot No.	1	1	2	2	3	3	4	4	5	5	6	6	7	7
Change in Frequency in Cycles	2400	670	800	1784	580	740	000	000	840	1550	675	445	375	300
BaO	X	X	X	.001	.002	.002	X	X	X	X	.001	.002	.001	X
Cr_2O_3	.001	X	X	X	X	.001	X	.001	X	X	X	X	X	.001
CuO	.009	.01	.008	.009	.008	.007	.008	.007	.006	.006	.006	.007	.006	.01
MnO_2	X	X	X	X	X	X	.001	.001	X	X	X	X	.001	X
TiO_2	.003	.002	.003	.002	.001	.001	.001	.001	.001	.001	.001	.001	.005	.001
MgO	.006	.005	.005	.003	.005	.006	.006	.003	.006	.006	.005	.004	.003	.003
ZrO_2	X	X	X	X	X	X	X	X	X	X	X	X	.003	X
CaO	.008	.006	.002	.003	.004	.003	.002	.005	.003	.003	.002	.003	.008	.003
Na_2O	X	X	XX	X	X	X	X	.001	X	X	X	X	X	X
K_2O	.001	.001	X	X	X	X	X	.001	.001	X	X	X	.001	.002
Li_2O	.005	.006	.003	.004	.006	.005	.004	.003	.003	.002	.001	.006	.001	.001
Cs_2O	.003	.002	.002	X	X	X	.001	X	X	X	X	.002	.002	.002
Rb_2O	X	X	X	.001	X	X	X	.002	X	.002	.002	X	X	X
Ag_2O	.001	X	X	.002	X	X	.001	X	X	X	X	X	.001	X
Al_2O_3	.008	.006	.007	.006	.008	.005	.008	.003	.004	.005	.006	.007	.004	.007

TABLE 7. SPECTROGRAPHIC ANALYSES OF OSCILLATOR PLATES (Cont.)

Lot No.	8	8	9	9	10	10	11	11	12	12	13	13	14	15	16
Change in Frequency in Cycles	2200	3000	210	1480	1500	1740	000	1400	820	1110	510	1240	470	290	420
BaO	X	.001	X	.001	.002	X	.001	.001	X	X	X	.002	X	X	X
Cr_2O_3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	.001
CuO	.006	.005	.008	.006	.006	.004	.006	.007	.006	.007	.008	.007	.008	.005	.007
MnO_2	X	X	.001	X	X	X	X	X	X	X	X	.002	.002	X	X
TiO_2	X	X	.001	X	.002	X	.001	X	X	.001	.001	X	X	.001	X
ZrO_2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MgO	.004	.003	.005	.005	.006	.002	.005	.006	.005	.004	.003	.003	.004	.004	.003
CaO	.002	.003	.005	.007	.004	.004	.006	.003	.004	.003	.004	.005	.003	.004	.004
Na_2O	X	X	X	X	X	X	X	X	X	.001	.001	X	X	X	X
K_2O	X	X	.001	.003	.002	X	.003	.001	X	X	X	.002	.001	X	X
Li_2O	.01	.004	.001	.004	.007	.005	.003	.004	.006	.005	.006	.004	.005	X	X
Cs_2O	.001	X	X	.001	.001	X	.001	X	X	.002	.001	X	X	X	X
Rb_2O	X	X	.001	X	X	X	X	.002	X	X	X	X	X	.001	.001
Ag_2O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Al_2O_3	.004	.004	.003	.004	.005	.004	.006	.008	.005	.004	.003	.004	.006	.003	.008

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* Spectrographic analyses were made by Mr. John C. Rabbitt of Harvard University.

RELATION BETWEEN SECONDARY DAUPHINE TWINNING AND IRRADIATION-COLORING IN QUARTZ[1]

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ABSTRACT

Either of two different structures may be assumed by a quartz crystal inverting to trigonal low-quartz from hexagonal high-quartz at 573° C. If the quartz is pure and perfect, the probability is the same for either choice. The fact that many crystals resume that particular low-temperature structure which they formerly had indicates imperfection.

Wide variability in the amount of darkening caused in different crystals by the same amount of X-ray irradiation must also indicate imperfection of some of the crystals.

A positive correlation has been found between these two phenomena, the most darkened crystals being those which resume most fully their former structures. A similar correlation is to be expected with other phenomena which have been found to vary widely in various specimens of quartz.

When a group of quartz plates exhibiting Dauphiné twinning is taken through the inversion temperature (573° ± 1° C.) to become high-temperature quartz the Dauphiné twinning is removed because the symmetry of high-quartz does not permit its existence.[2] When the plates are then cooled through the inversion temperature to become low-quartz again the Dauphiné twin-boundaries, distinguishable by etching, may or may not reappear in their original positions. Quite commonly they do resume their former positions, a phenomenon which indicates that the quartz in which this occurs is not perfect quartz, since in perfect quartz the probability of a twin boundary recurring in the same location after inversion would be extremely low. Some structural irregularity, possibly due to the presence of vary small amounts of impurities, must determine which of the two possible orientations is assumed by the quartz at the moment of inversion to the trigonal, low-temperature form.

Other observations have indicated that different specimens of colorless, water-clear quartz have different properties and are, therefore, not all perfect quartz. Measurements of the electrical conductivity of quartz along the optic axis have yielded such various results that, according to R. B. Sosman,[3] "the true axial conductivity of the pure crystal is quite unknown."

In the course of some recent experiments on the effect of X-ray irradiation on the oscillation-frequency of quartz oscillator plates, an effect first described by Frondel,[4] the writer found widespread individual differences in the amount of coloration and frequency-alteration among various plates given the same treatment, some showing marked frequency change and becoming brownish black after two hours of X-ray irradiation while others, similarly treated, changed frequency only slightly and were only faintly darkened.

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[1] Armstrong, E., Relation between darkening by X-ray irradiation and permanence of Dauphiné twinning in quartz: *Phys. Rev.*, **68**, 282 (1945). Abstract.

[2] Dauphiné twin law: 180° rotation around the *c*-axis, an axis of three-fold symmetry in low-quartz, six fold symmetry in high-quartz. For a fuller discussion, see Frondel, Secondary Dauphiné twinning in quartz: *Am. Mineral.*, **30**, 447–460 (May–June, 1945).

[3] Sosman, R. B., The Properties of Silica, New York (**1927**) p. 528.

These individual differences again indicate impurity, or structural imperfection, and a positive correlation might therefore be expected between alteration by irradiation and the resumption of a former orientation after inversion.

To determine whether such a correlation does exist, forty-five quartz plates,[5] 18 mm. square and ½ mm. thick, were treated as follows. The plates were first etched for 20 minutes with 48% hydrofluoric acid at 25° C. so that the distribution of the Dauphiné twinning, if present, would be visible. The photographs in rows A_{1-5} of Figs. 1 and 2 were taken after this first etch. The plates represented were colorless clear quartz. The dark and light areas in the photographs are due to the different reflectivities of the differently oriented regions of the plate when obliquely lighted.

The plates were then heated to approximately 600° C. and cooled to room temperature.[6] The etch patterns resulting from their former orientation were removed by lapping with 303½ emery and the plates were re-etched. The photographs in rows B_{1-5} of Figs. 1 and 2 were taken after the heating and second etch. Each plate was then irradiated for two hours with X-rays from a copper target tube, operating at 60 kv. and 25 ma., lightly lapped to remove the etch pattern and photographed. These photographs are shown in rows C_{1-5} of Figs. 1 and 2 in which the dark and light portions represent dark and light quartz, not differences in reflectivity.

Because of beam-size limitations only an oval or half-oval portion of each plate was irradiated. Therefore only these oval darkened portions of the plates in rows C_{1-5} are concerned in the present discussion.

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[4] Frondel, Clifford, Frequency adjustment of quartz oscillator plates by *x*-rays: *Radio Engineer's Digest*, pp. 32–52 (Oct. 1944).

Frondel, Clifford, X-ray adjustment of quartz plates: *Electronic Industries*, pp. 98–110, 166, 168, 170 (December, 1944).

Frondel, Clifford, Effect of radiation on the elasticity of quartz: *Am. Mineral.*, **30**, 205–468 (May–June, 1945).

[5] "BT Plates," oriented parallel to an *a*-axis and 49° from the *c*-axis.

[6] Since the rate of temperature change may have exceeded 10° per minute over short periods of time some of the twinning produced could have resulted from thermal strain as described in Frondel's paper (footnote 9) which had not yet been published when this work was done.

The 36 sets of photographs in Fig. 1 have been arranged in order of decreasing darkening resulting from the irradiation. It is apparent that there is a rough correlation between irradiation-darkening and the resumption of original orientation after inversion, as anticipated. Plates that become very dark after two hours' irradiation show unchanged twin-boundaries after having been heated to more than 573° C., while plates in which the coloration is almost imperceptible show markedly changed twin-boundaries, commonly with an intricate pattern. An untwinned plate which becomes very dark with two hours' irradiation remains untwinned when taken through the inversion temperature while an untwinned plate that is only faintly darkened by irradiation becomes twinned when taken through the inversion temperature. Between the extremes there is every gradation of alteration by irradiation and the correlation with resumption of previous orientation in this region has not yet been fully explored. A tabular analysis of the data is given in Table 1.

Table 1. Analysis of Changes Shown in Figure 1

Original Condition→		Twinned			Untwinned		
Effect of Inversion→		Change (Boundaries Changed)	No Change (Boundaries Recaptured)		Change (Twinning Introduced)	No Change (Untwinned State Recaptured)	
			Exactly	Almost Exactly		Completely	Almost Completely
Order of decreasing darkening by irradiation	Row 1		3	2		5	2
	Row 2	1	1	2	4	4	
	Row 3	3	1		6	2	

This correlation between darkening by X-ray irradiation and resumption of previous orientation after inversion was first observed by Zinserling[7] who interpreted it as the result of "impurities penetrating in the course of trigonal quartz growth" occupying in the lattice "a stable position corresponding to the trigonal symmetry" of low quartz, determining which trigonal orientation shall be assumed by the quartz after inversion.

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[7] Zinserling, E. V., Quartz twinning control under alpha-beta inversion: *Compt. Rend. Acad. Sci. U.R.S.S.*, **33**, 365 (1941).

Zinserling, E. V., Quartz colouring as dependent on its twinning capacity under alpha-beta conversion: *ibid.*, **33**, 368, (1941).

Zinserling, E. V., and Laemmlein, G. G., Conversion of a negative quartz rhombohedron into a positive one as a result of alpha-beta transformation: *ibid.*, **33**, 419 (1941).

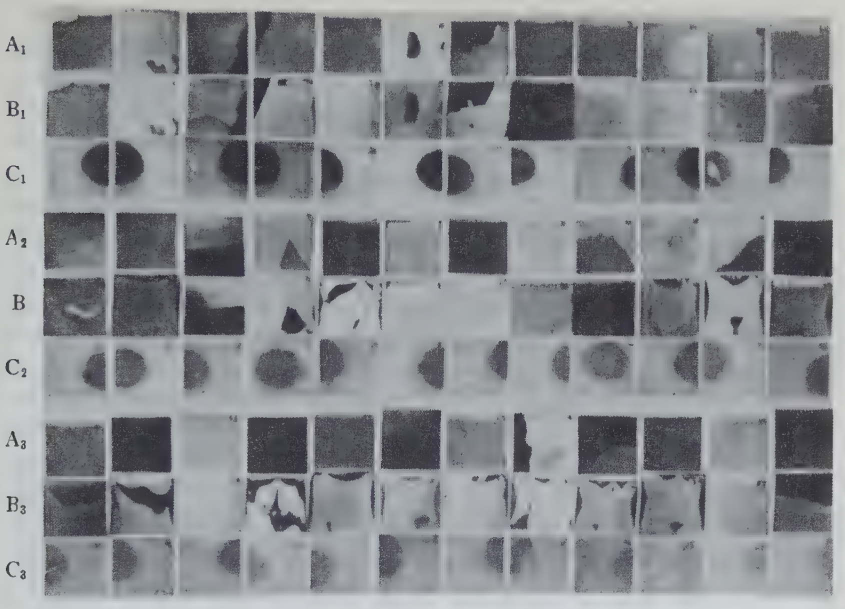

FIG. 1. Photographs of quartz plates etched to show twin pattern before (*A*) and after (*B*) heating through the inversion temperature (573° ± 1° C) and of the same plates after irradiation (*C*).

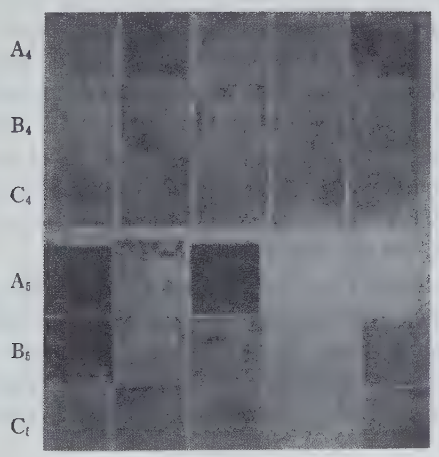

FIG. 2. Photographs of quartz plates etched to show twin pattern before (*A*) and after (*B*) heating through the inversion temperature (573° ± 1° C) and of the same plates after irradiation (*C*).

Mott and Gurney[8] ascribe the X-ray coloration of pure alkali halide crystals to lattice defects and, pending further evidence, both hypotheses should be kept in mind. The nine plates in Fig. 2 were photographed separately because they illustrated localization of orientation-change in the lighter colored parts of plates unhomogeneously colored by irradiation. In most cases this is not well shown in the photograph. In Plate 7 (fourth plate in Rows A_4–C_4), which shows it most clearly, all changes of orientation due to inversion (cf. 7 in row A_4 and 7 in row B_4 of Fig. 2) took place below a line bisecting the plate horizontally for most of its length and turning through 120° to slope downward at its right end. (The roughly rhomb-shaped medium gray region is a region of Brazil twinning which persists in high-quartz and is therefore, of course, not altered by the inversion.) After irradiation the plate appeared distinctly less colored within the region containing the new twinning than outside of it, showing that the quartz was forced to resume its former orientation in the darkly colored portion while in the lighter (more perfect) portion it was free to assume either of the two possible orientations.

In a recent paper in this journal,[9] Frondel shows four plates unhomogeneously colored by irradiation in which, as in the case of plate 7, Fig. 2 those parts of the plates that have not resumed their former orientation are almost wholly within the regions least affected by the irradiation. Frondel is here illustrating a statement which the writer's experiments also support, that when quartz containing smoky zones is irradiated, the originally lighter or colorless portions are always more deeply affected by the radiation, whether or not the smoky color was removed by heating prior to the irradiation. This observation correlates well with the observation that smoky quartz more readily changes its orientation according to the Dauphiné twin law, whether by inversion at high temperature, as illustrated in Frondel's Fig. 7, page 63,[9] or by applied stresses at lower temperatures, as illustrated in Frondel's Fig. 5, page 60.[9] The correlation is presented in tabular form in Table 2.

The results shown in Fig. 1 are not in accord with Frondel's statement (p. 64)[9] that "randomly selected colorless or uniformly tinted BT quartz plates when re-inverted at 573° C. are found, on a statistical basis, to be very much more disposed to secondary twinning when Dauphiné twinning is originally present than absent, although, as noted

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[8] Mott, N. F., and Gurney, R. W., Electronic Processes in Ionic Crystals, Oxford (**1940**), p. 112.

[9] Frondel, C., Secondary Dauphiné twinning in quartz produced by sawing. Irradiation of twinned quartz: *Am. Mineral.*, **31**, 58–64 (Jan.–Feb., 1946).

TABLE 2. SUMMARY OF INTERPRETATION OF RESULTS

Original Color	Effect of Irradiation with X-rays	Probability of Change of Orientation According to Dauphiné Law, Either by Inversion or by Applied Stress	Interpretation
Smoky	Relatively weak	Relatively high	Less Imperfect
Clear	Relatively weak	Relatively high	Less Imperfect
	Relatively strong	Relatively low	More Imperfect

above, there is seemingly no tendency to exactly recapture the original twin boundaries." Table 1 shows that those plates which could be strongly darkened by irradiation did show a tendency to recapture the original twin boundaries and that the incidence of secondary twinning is correlated with inability of the quartz to take on color when irradiated rather than with the original presence of a Dauphiné twin-boundary within the limits of the cut plate.

RADIOCOLLOID AGGREGATES IN URANIUM MINERALS

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Abstract

Radiocolloid aggregates have been observed in the alpha ray pattern of altered uranium minerals. Properties of laboratory prepared radiocolloids suggest that the naturally occurring aggregates were probably composed of radium sulfate at the time of deposition. The radiocolloids exhibit at present an alpha ray activity about 50 times greater than that of normal uraninites. Their present day composition is essentially $Pb^{206}SO_4$ with about 0.003 per cent $RaSO_4$ as deduced from chemical and radiographic tests. This represents a 150-fold concentration of radium over that normally present in equilibrium with uranium.

Introduction

Radiochemical studies show that in dilute solutions of radioactive salts the solutes exist not only as individual ions, but also as discontinuous aggregates. These units have been designated radiocolloids, as they can be separated from the aqueous phase by centrifugation, dialysis and electrophoretic methods. The aggregates also exist in the gaseous state and have been observed by Harrington (5) during ultramicroscopic examination of radon tubes. The properties of the radiocolloids of the naturally occurring radioactive elements are described by Hahn (3) and Haissinsky (4). More recently, Kurbatov (7) has shown that this phenomenon also exists in solutions containing synthetic radioactive isotopes of the lighter elements. It permitted the isolation of radioyttrium from the solution of a deuteron bombarded strontium oxide target without the aid of a carrier.

The presence of atomic aggregation is readily demonstrated by the photographic method devised by Chamie (1, 2). The decay of isolated atoms is recorded by the silver bromide emulsion as individual tracks. Where aggregation exists, the developed pattern consists of a black core surrounded by a halo of radiating tracks produced by alpha particles striking the emulsion at glancing incidence. Structures typical of radiocolloid aggregation are exhibited in prints A and B of Fig. 1, showing microscopic details of the alpha ray pattern of a polonium film deposited electrolytically from acid medium on a copper disk.

Radiocolloids in Uranium Minerals

Microscopic examination of alpha ray patterns (10) from a series of polished sections of a single crystal of uraninite externally altered to gummite revealed minute structures of unusually high alpha ray activity in the altered portions, particularly the crystal tip (Fig. 2, *D*). Comparative photomicrographs (Fig. 1, *C* and *D*) of the alpha ray patterns produced by the gummite and the polonium film show a striking similarity in form. The radiographic images of the aggregates in the gummite range between 30 and 170 microns in diameter but the structures in the mineral are undoubtedly smaller as the image is enlarged by scattered and oblique alpha radiations. The gray background (Fig. 1, *D*) produced by the normal alpha ray activity of the gummite matrix obscures the finer detail of the halo, but furnishes a comparative basis for demonstrating the intense activity of the aggregates.

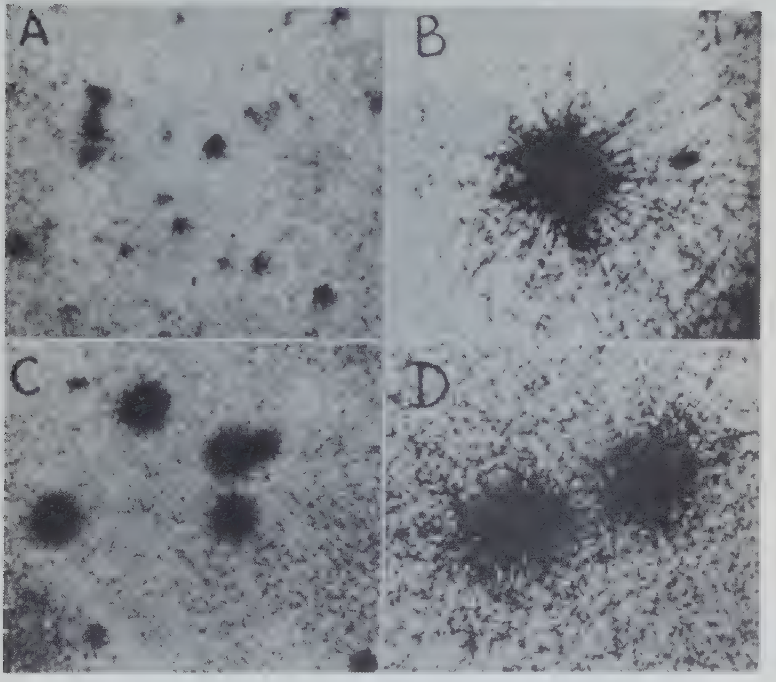

Fig. 1. Comparison of Laboratory and Native Radiocolloid Aggregates.

(*A*) alpha ray pattern of polonium film (38×) showing dark aggregates on a background of individual tracks from decay of polonium atoms.

(*B*) Single polonium radiocolloid at 280× showing tracks in halo.

(*C*) Radiocolloids in alpha ray pattern of gummite (38×) revealing several small aggregates comparable with those in print (*A*) and larger units usually not encountered in laboratory preparations.

(*D*) Radiocolloids in gummite at 200×. The fine detail of the halo is obscured by background alpha radiation from the matrix.

Study of Plate 1 shows that the individually resolvable radiocolloids have no visible point counterparts on the mineral surface, suggesting that the radiation emerges from units held in solid solution by the matrix. The macro regions of high alpha ray activity conform, in part, with the position of fine fissures on the polished section. These structures may contain radiocolloid aggregates in too close proximity for radiographic resolution. The point images correspond either to minute spheres or fine veins of radioactive matter intersected at right angles by the cutting plane. The former structure seems more probable, as the removal of about 100 microns thickness by repolishing causes the disappearance of the original point aggregates in the new pattern, whereas the fissure depositions persist. Also, the individual radiocolloid structures are rarely observed, while the fissure type of deposition is of frequent occurrence in altered uranium minerals, particularly along an interface. A striking example of such deposition on a border between uraninite and uranophane is shown in Fig. 3.

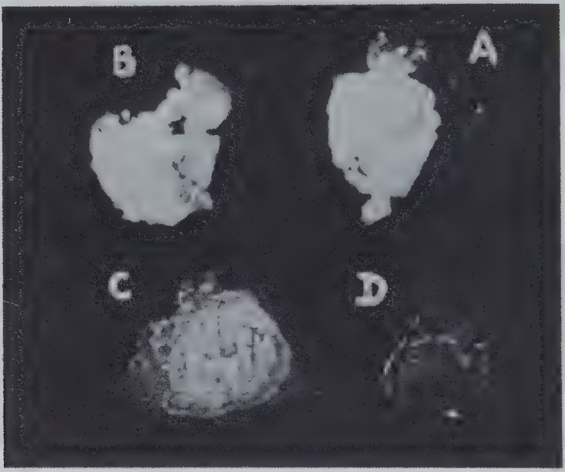

FIG. 2. Alpha Ray Pattern of Serial Sections of Altered Uraninite Crystal. Positive print (1×). Crystal from Brush Mineral Collection, Yale University. Found in a pegmatite located in Colombia, S. America.

(*A*) and (*B*) shows unaltered uraninite with several minute internal fissures.

(*C*) Pattern shows residual core of uraninite (gray) surrounded by alteration products.

(*D*) Apex of crystal completely altered to gummite. Note segregated regions (white) which exhibit an alpha ray activity exceeding unaltered uraninite (*A*) and (*B*).

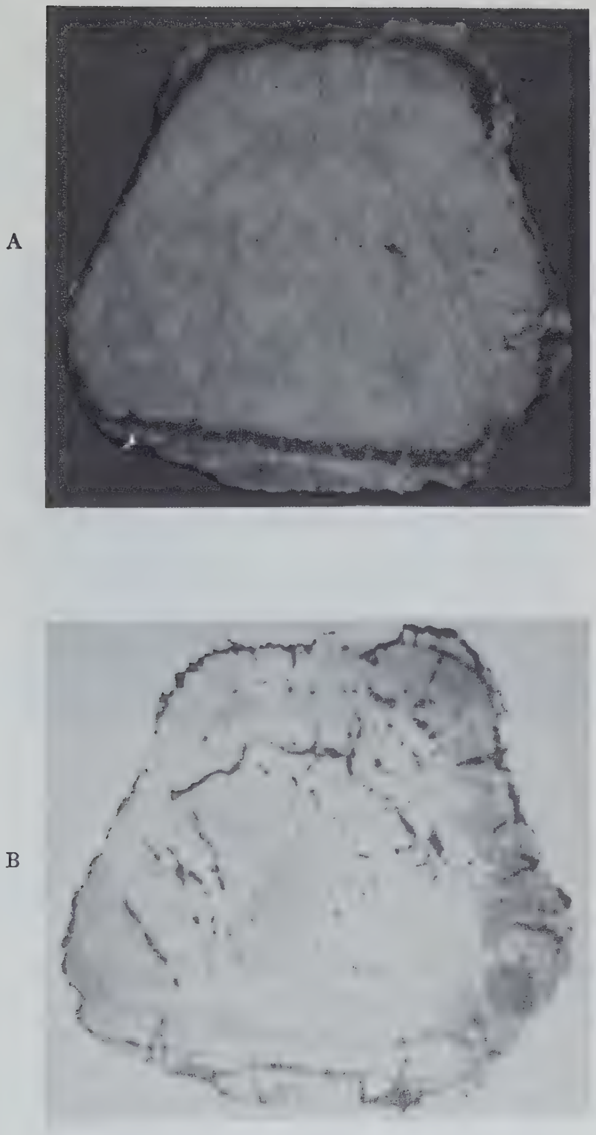

Plate 1. Comparison of Polished Gummite Section and Its Alpha Ray Pattern.
(*A*) Macrograph (5×) of gummite under oblique annular illumination.
(*B*) Macrograph (5×) of alpha ray pattern.

Examination of available patterns revealed the presence of individually resolvable radiocolloids in only three additional polished sections. These occurred in autunite from Mt. Painter, South Australia (U. S. National Museum 91921), a pitchblende from Shinkolobwe, Belgium Congo (U. S. National Museum 104784) and in a quartz-pitchblende section from Great Bear Lake, Canada (U. S. National Museum R-6736). Examination of the alpha ray patterns furnished by primary thorium minerals (monazite, thorianite and thorite) failed to show the presence of radiocolloid aggregates.

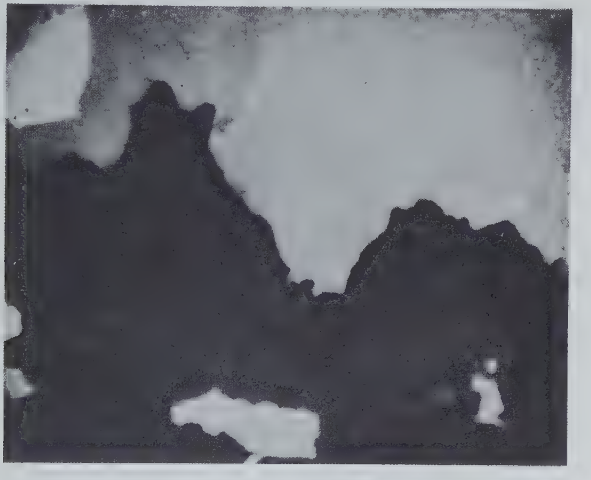

FIG. 3. Deposition of Radiocolloids Along Interface. Detail from alpha ray pattern (10×) showing zone of radiocolloid deposition (black) between uraninite (dark gray) and uranophane (light gray). The white inclusions are cyrtolite whose feeble radioactivity is not reproduced in the print. The zone of high alpha ray activity is revealed as a fine line of lead dithizonate on the ammonium acetate-lead pattern. Specimen collected by author at Spruce Pine, Mitchell Co., N.C.

The pattern produced by the Great Bear Lake pitchblende proved of particular interest as some of the radiocolloids were deposited in the quartz veins between the colloform structures of the pitchblende and these produced images unobscured by background radiation. The halo in the radiocolloid reproduced in Fig. 4 contains alpha ray tracks having a range in the emulsion of 53 ± 2 microns. This is equivalent to an air range of 6.8 ± 0.2 cm. and identifies the tracks as originating from RaC′. The core has an apparent diameter of 150 microns. Close examination of the same area on the polished surface did not reveal a black pitchblende inclusion of comparable size. However, the quartz showed an iridescent halo of about 90 microns diameter at the correlating point. Since the range of RaC′ alpha rays in quartz is 37 microns, and the iridescent halo probably corresponds to the terminus of the alpha ray track, the diameter of the radiocolloid aggregate is estimated at about 15 microns.

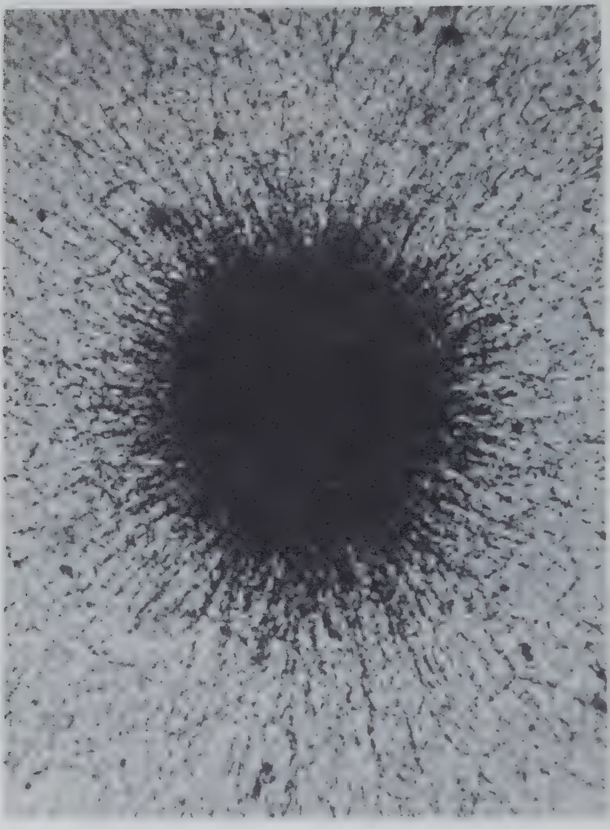

Fig. 4. Radiocolloid Aggregate Deposited in Quartz Adjacent to Pitchblende. Photomicrographic detail at 550× (reduced ½ in reproduction) from alpha ray pattern of Great Bear Lake, Canada pitchblende.

Possible Origin of the Radiocolloids

The radiocolloids deposited in the quartz are apparently unassociated with any parent uranium mineral. Examination of the polished surface under oblique annular illumination at the points corresponding to the location of the aggregates do not reveal particles with the color of pitchblende or its colored alteration products. Under vertical illumination with polarized light the points of high alpha ray activity are revealed by a reflectivity intermediate between the pitchblende and that of the quartz. The white particle enclosed in the inscribed rectangle (Fig. 5, *A*) corresponds to the geometric center of the radiocolloid image in the alpha ray pattern, *B*. Under higher magnification (Fig. 5, *C*) the point of origin is resolved into an apparent capillary structure of smaller circular areas having diameters between 1–2 microns.

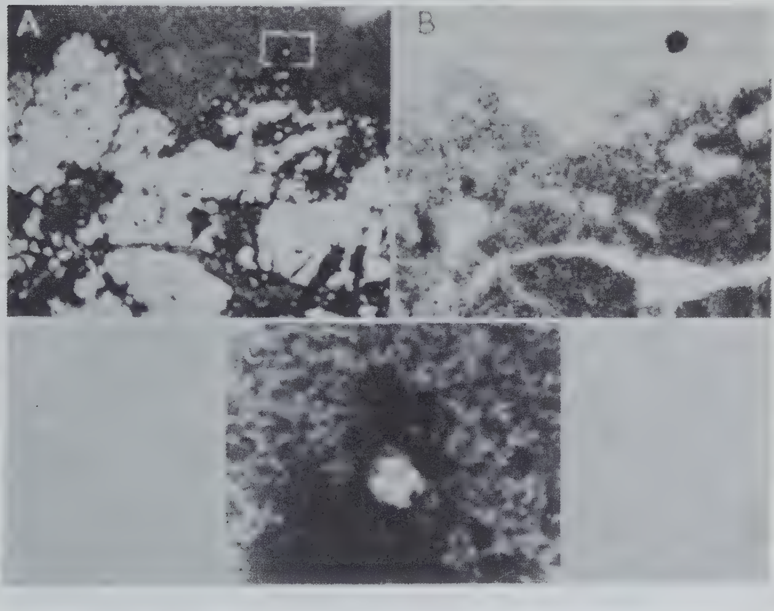

FIG. 5. Orientation of Radiocolloid in Polished Section.

(*A*) Photomicrograph (41×) of Great Bear Lake, Canada pitchblende under vertical illumination, showing pitchblende (white), quartz (gray) and altered pitchblende (black).

(*B*) Photomicrograph (41×) of corresponding area of alpha ray pattern.

(*C*) A 7× enlargement of point in polished section producing radiocolloid image.

The measurement of the photographic density of the radiocolloid images is rendered difficult by their minute size and extreme blackness. The alpha ray activity can be approximated by counting the RaC′ tracks in the halo and assuming that the resolvable tracks represent 5/90 of the total directed towards the emulsion. The radiocolloid reproduced in Fig. 4 contains about 100 tracks in the halo whose length is indicative of RaC′ origin. Thus, during the 100 hr. exposure producing the image, about 1800 RaC′ particles penetrated the emulsion accompanied by an equal number of rays from the decay of radium, radon, radium A and polonium. This corresponds to a P_α value of 16,000 per sec. per sq. cm., a value greatly exceeding that of the purest primary uranium minerals ($P_\alpha = 338$), and considerably smaller than the rate of emission from equilibrated radium sulfate estimated at 5×10^8 per sec. per sq. cm.

The abnormal rate of decay of the radiocolloid areas is explicable on the assumption that a substantially pure radium compound deposited in the capillaries, which decaying in the absence of regenerating material, diminished in abundance to correspond with the observed intermediate rate of disintegration. The initial formation of micro inclusions of radium sulfate can be explained in terms of two well established properties of radiocolloids. First, that the aggregates form at extreme dilutions far below the saturation point of the insoluble salts of the same composition, and secondly that the radiocolloids are readily adsorbed on porous materials. The latter property is particularly exhibited by dilute solutions of radium sulfate (saturation concentration at 20° is only 1.4 mg. per liter) which on passage through filter paper deposit 98 per cent of the radium on the cellulose fibers (3).

Descriptions of the Great Bear Lake pitchblende deposits (6, 9) show the presence of sulfur minerals and that the exposed pitchblende veins weather readily. Surface waters containing traces of sulfuric acid dissolve the alteration products forming a dilute solution of the metallic constituents, including the uranium and the radium in equilibrium with it. In an acid solution containing sulfate ions, the radium would exist as radiocolloids of the acid insoluble radium sulfate. Since uranium is not known to form radiocolloids in acid media it will exist dissociated as uranyl ions. When the solution passes through fissures in the quartz the aggregates deposit on the walls of the capillaries producing a filtrate substantially devoid of radium. Whether this simplified picture describes the exact mode of deposition is conjectural, but that a mechanism exists for the separation of radium from uranium solutions is shown by the occurrence of hydrated uranium minerals, such as autunite, which are practically devoid of their normal alpha ray activity (10) on the surface of pegmatite rocks.

The radium no longer in equilibrium with uranium or ionium decays rapidly with the formation of radiolead. From the observed rate of decay of the radiocolloids, it is possible to estimate the approximate time of their deposition by means of the law of radioactive decay, $P_\alpha = P^0_\alpha e^{-\lambda t}$. Assuming the initial composition to be radium sulfate free from ionium, the age of the radiocolloids investigated is about 20,000 years. Owing to the rapid rates of decay of radium and its equilibrium products, the present composition of the radiocolloids is essentially $Pb^{206}SO_4$ associated with about 0.003 per cent $RaSO_4$. This represents a 150-fold concentration of radium in the aggregates as compared with the radium in equilibrium with the uranium in pitchblende.

Radiocolloid formation is probably a fairly common phenomenon in pitchblende deposits. Regions of high radioactivity have been recorded by Spence (8) in autoradiographs of Great Bear Lake pitchblende, and highly radioactive veinlets and dots in the mineral have been noted by Kidd and Haycock (6). The writer has observed essentially the same phenomenon in two separate samples from the Katanga, Belgium Congo deposit, the radiocolloids occurring in the veinlets of the yellow alteration products permeating the pitchblende. Individually resolvable radiocolloids were also observed in sections prepared from a highly altered pitchblende from St. Just, Cornwall, England.

Lead Patterns of Radiocolloid Areas

If the radiocolloids are composed of lead sulphate, as deduced from the mechanism of their formation, it should be possible to confirm this composition by means of the solvent action of ammonium acetate on this compound. The sections exhibiting radiocolloids were pressed against gelatin paper moistened with $2n\text{-}NH_4C_2H_3O_2$ and after one minute contact the paper was treated in succession with the following solutions: 5 per cent K_2CrO_4 (1 min.), 5 per cent acetic acid (2 min.), water (5 min.), 0.1 per cent dithizone in 10 per cent KCN (30 sec.) and running wash water for 15 minutes. The pattern of the pitchblende (Fig. 6) showed the presence of extractable lead only on the areas bordering the quartz where the radiocolloids are concentrated. Comparative microscopic observations revealed red points of lead dithizonate coincident with points of high alpha ray activity and also groups of circular lead areas which had no equivalent counterparts of high photographic density on the radio-

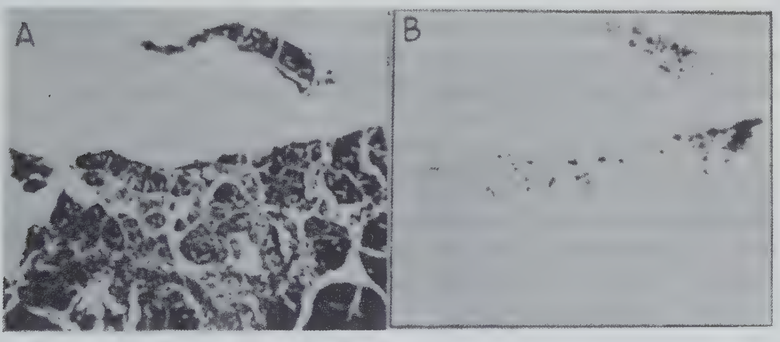

Fig. 6. Comparison of Alpha Ray and Extractable Lead Patterns of Great Bear Lake Pitchblende.

(*A*) Alpha ray pattern ($3\frac{1}{3}\times$).

(*B*) Ammonium acetate lead pattern ($3\frac{1}{3}\times$).

graph. The latter points probably correspond to older radiocolloids in which the radium has decayed to an activity comparable with that of the pitchblende. It is noteworthy that the unaltered pitchblende, holding about 10 per cent radiolead in solid solution, does not furnish an extractable lead pattern.

Tests on other polished sections showed that macro regions of abnormal alpha ray activity furnished a positive extractable lead pattern. The reaction is given by massive plumbian uranate minerals, such as curite and kasolite. Galena does not furnish a lead print by this mechanism. Ammonium acetate also exerts a solvent action on other sparingly soluble lead compounds and positive lead prints were obtained from polished sections of cerussite, $PbCO_3$, calcium larsenite, $(Pb,Ca)ZnSiO_4$ and pyromorphite, $3Pb_3P_2O_8 \cdot PbCl_2$. Thus, although the method is not definitive for lead sulfate, the absence of colored secondary inclusions in the pitchblende coupled with the insolubility of radium sulfate in acid solutions, limits the present day composition of the radiocolloids to lead sulfate. This printing procedure promises to be of utility in the study of the distribution of lead in radioactive minerals and further details will be presented in a report on the extractable and total lead patterns.

Summary

The occurrence of radiocolloids in altered uranium minerals is not only of interest in showing a parallelism to a phenomenon known previously only in the laboratory, but their existence offers an explanation for the formation of zones of abnormally high alpha ray activity in minerals. A mechanism is described whereby radium is separated from uranium as a result of radiocolloid formation in acid media, and chemical evidence is presented identifying the lead resulting from the localized decay of the radium.

Acknowledgments

It is a pleasure to acknowledge the cooperation of E. P. Henderson of the U. S. National Museum in providing specimens used in these studies.

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4. Haissinsky, M., Les Radiocolloides, Hermann & Co., Paris (1937).
5. Harrington, E. L., *Phil. Mag.* (7), **6**, 685–695 (1928).
6. Kidd, D. F., and Haycock, M. H., *Bull. Geol. Soc. Am.*, **46**, 879–960 (1935).
7. Kurbatov, J. D., and Kurbatov, M. H., *J. Phys. Chem.*, **46**, 441–457 (1942).
8. Spence, H. S., *Can. Min. Jour.*, **53**, 483 (1932).
9. Spence, H. S., *Can. Dept. Mines, Bull.* No. **727–3**, Ottawa (1932).
10. Yagoda, H., *Am. Mineral.*, **31**, 87–124 (1946).

A STUDY OF THE SALT SPRINGS ROAD PERIDOTITE DIKE IN SYRACUSE, NEW YORK

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Contents

Abstract 471
Introduction 471
Location of the Dike 472
Geology of the Occurrence 473
Preliminary Treatment of the Samples 474
Petrography of the Residual Fragments 475
Mineralogy 476
Chemical Characteristics 479
Specific Gravity 480
Calculations 481
General Discussion and Conclusions 484
Acknowledgments 485

Abstract

The Salt Springs Road dike occurs near the intersection of Salt Springs Road and East Genesee St., Syracuse, N. Y. It intrudes the nearly horizontal Camillus formation of the Silurian system as a steeply dipping dike approximately 51 inches wide. The dike now, largely altered, consists of small grains, small composite fragments and yellowish-green, friable masses that are occasionally porphyritic in appearance. Geologic, petrographic and chemical studies indicate that the material of the dike was formed from the weathering of a serpentine rock, which in turn resulted from the alteration of an igneous rock of the peridotite group.

The altered dike consists, primarily, of vermiculite with somewhat less serpentine. Magnetite, limonite, perovskite and clay minerals are relatively abundant in the altered material. In addition there are small quantities of olivine, phlogopite, apatite, quartz, carbonates, andesine and tremolite present. The relict minerals are small amounts of magnetite, perofskite, apatite, olivine and perhaps chromite.

From the chemical and petrographic data the unaltered rock is according to Johannsen's classification, a mica peridotite. class 4, order 1, family 5, (415).

Introduction

Slightly over 100 years ago the first igneous dike, now known as the Green Street dike, was discovered in Syracuse, N. Y., and reported by Vanuxem.[1] During this period a number of such dikes were discovered in central New York. One of these was exposed along Thompson Road just outside of the eastern city limits; it is now known as the Dewitt dike because of its occurrence at the Dewitt reservoir. A bibliography of the geology and petrography of these dikes is given by Clark,[2] and by Hopkins.[3]

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[1] Vanuxem, Lardner, *Geological Survey of New York*. 3d an. Rept. of the Geol. Surv. of 3d Dist. (**1839**), 160 and 283.

The most recent dike to be recorded[4] is the subject of this paper. It is known as the Salt Springs Road dike, and was brought to Ploger's attention in the Spring of 1921 by Arthur E. Brainerd then Professor of Geology at Syracuse University. A geologic study of the dike and the surrounding area was made at that time, and samples were collected for laboratory investigation. These have now been studied with the results here reported.

Location of the Dike

The Salt Springs Road dike was exposed during an excavation for a sewer along the north side of Salt Springs Road, Syracuse, N. Y., about midway between Bruce St. and Fenway Drive, and approximately 200 feet east of the intersection of Salt Springs Road and East Genesee St. A scanty exposure of what is thought to be the same dike was seen on a newly graded lawn, and along the sidewalk, on the north side of East Genesee St. directly south of the exposure on Salt Springs Road. No detailed examination of this location was feasible at the time, nor has it been since. These exposures are now covered by lawns, sidewalks, and pavements. The location of the dike is shown in Fig. 1.

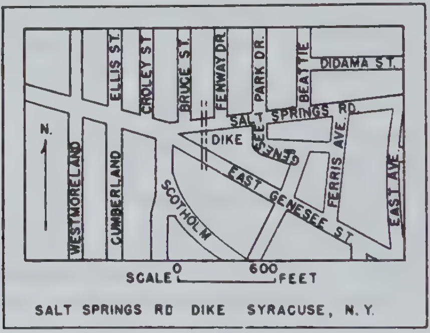

Fig. 1

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[2] Clark, Burton W., The peridotite dikes of Onondaga County, New York. Masters Thesis, Syracuse University Library (**1908**).

[3] Hopkins, Thomas C., The Geology of the Syracuse Quadrangle: *New York State Museum, Bull.* **171**, 53–56 (1914).

[4] Maynard, James E., and Ploger, Louis W., An unrecorded altered peridotite dike in Syracuse, N. Y.: *Am. Mineral.*, **31** 200–201 (1946). Abstract.

Geology of the Occurrence

The dike at Salt Springs Road is about 51 inches wide, and at the time of observation was exposed to a depth of slightly more than 5 feet. It was decomposed by weathering, almost completely disintegrated so as to consist of a yellowish-green earthy material made up dominantly of a mixture of sand-size particles and larger friable lumps. When pulverized with the fingers residual hard kernels were recovered from some of the lumps; a few of these were about as large as peas, the average being about 3 mm. in diameter. The rounded forms of the kernels resembled very closely those that are commonly found in igneous rocks that are undergoing weathering, and where all stages are represented from completely weathered material to fresh unaltered rock.

Examination of the larger residual fragments with a hand lens showed small greenish-brown rounded grains distributed throughout a finer grained matrix, producing a distinctly porphyritic-like appearance. The shape, arrangment and aspect of the grains strongly suggested serpentine pseudomorphs after original olivine phenocrysts.

The altered dike was penetrated by rootlets, up to one half inch thick, to the bottom of the exposure. This condition contrasted markedly with the complete failure of such roots to penetrate the country rock on either side of the dike.

The country rock is dominantly shaly limestone, and shale, and is referred to the lower member of the Camillus of the Salina group. The strata of this formation normally have a gentle dip in a southerly direction in this region. Within the first few feet adjacent to the dike on both the east and west sides, the pressure of the intrusion caused an appreciable dip of the strata away from the dike, with an angle reaching a maximum of 45° on the east side. The dike itself dips eastward at an angle of about 82°. An effect resembling slaty cleavage appears in the shale on the east side of the dike and closely adjacent to it, and was probably induced by the pressure of the intrusion.

A zone 8 to 10 inches wide on the west contact, and 10 to 12 inches on the east contact showed a whitish powdery surface that may have been produced by heat during the intrusion of the dike.

On the east side of the dike and in contact with its upper part is a deposit of Pleistocene conglomerate, occupying an erosional hollow to a depth of about 3 feet. To the west of the dike and sloping in the direction of Salt Springs Road, is a north-south hollow now partly occupied by fill. The origin of the hollows may have a bearing on when the weathering of the dike took place. Their position on either side of the dike at least suggests that the dike was relatively unweathered during the Pleistocene, and, therefore, more resistant than the softer country rock on either side to erosion and to the thrusting action of the Pleistocene ice sheet advancing from the north-northwest. The data, however, are inadequate to draw definite conclusions, either as to when the depressions were formed or when the weathering of the dike took place. An east-west structure section across the dike is shown in Fig. 2.

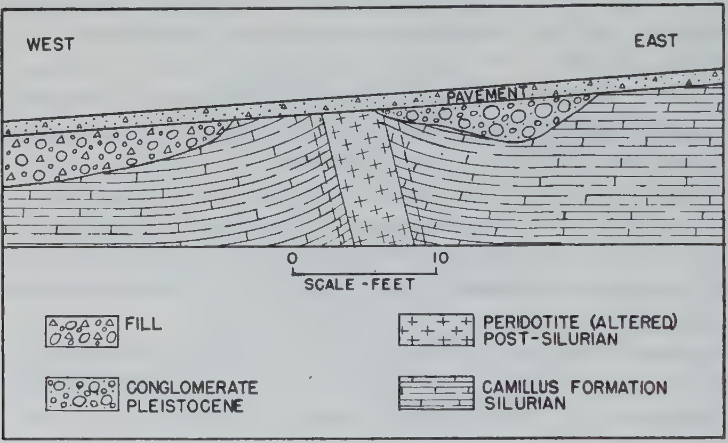
WEST
EAST
PAVEMENT
0
10
SCALE - FEET
FILL
CONGLOMERATE PLEISTOCENE
PERIDOTITE (ALTERED) POST-SILURIAN
CAMILLUS FORMATION SILURIAN

Fig. 2. Structure Section Through the Salt Springs Road Dike in Syracuse, N. Y.

PRELIMINARY TREATMENT

For the purpose of facilitating petrographic and mineralogic study, and to obtain information on the state of disintegration of the material, a large quantity was separated into fractions by sieving with a Tyler automatic "Ro-Tap" shaker. The weight percentages of the separates, according to the Wentworth grade scale, are given in Table 1.

Table 1. Mechanical Analysis of Altered Rock

	Per Cent by Weight
Pebble, 64 to 4 mm.	3.5
Granule, 4 to 2 mm.	3.5
Very coarse sand, 2 to 1 mm.	4.9
Coarse sand, 1 to 0.5 mm.	8.4
Medium sand, 0.5 to 0.25 mm.	4.9
Fine sand, 0.25 to 0.125 mm.	27.5
Very fine sand, 0.125 to 0.062 mm.	19.2
Silt and clay, below 0.062 mm.	30.1
	100.0

The mechanical analysis shows very clearly that the rock is in an advanced stage of disintegration; approximately 75 per cent of it is finer than medium sand. Microscopic examination of the separates shows that all grades coarser than very fine sand consist dominantly of aggregates. The very fine sand and the grades below it consist dominantly of monomineralic grains. Many relatively hard and still coherent fragments of rock occur in the pebble and granule grades. Practically all of the composite grains in the larger grades are friable and can be disintegrated by rubbing with the fingers.

PETROGRAPHY OF THE RESIDUAL ROCK FRAGMENTS

Under the microscope many of the pebbles and granules show a well defined porphyritic texture. Most of the phenocrysts are serpentine, but they have the typical rounded and angular outlines of olivine; a few show residual cores of olivine; some are surrounded by rims of brown phlogopite. They average about 1.0 mm. in size, but occasionally an individual grain may reach 2.0 mm. Phenocrysts of phlogopite averaging 8 mm. in size are rare.

The groundmass is largely a fine-grained aggregation of vermiculite and serpentine. Iron oxides, both magnetite and limonite, and perofskite are prevalent. Apatite occurs in minor amounts. Part of the magnetite is automorphic which strongly suggests that at least some of it may be primary. Most of the perovskite and apatite are also automorphic and probably original constituents. Clay minerals, quartz, carbonates, and chromite were not identified in the groundmass of the fragments.

Volumetric measurements on many pebbles and granules gave: serpentine phenocrysts 32.0 per cent; groundmass 68.0 per cent. These values indicate that olivine constituted at least 34.0 per cent of the unweathered rock.

No satisfactory quantitative determinations could be made on the relative abundance of the various minerals in the groundmass. By inspection, vermiculite and serpentine appear to be present in about equal proportions and constitute three fourths of it; the balance is about equally distributed between magnetite, limonite, and perovskite.

The geologic studies together with the petrographic data show that the altered material now constituting the Salt Springs Road dike was formed from the weathering of a serpentine rock high in mica, and that this serpentine rock resulted from the alteration of a basic igneous rock of the peridotite group. The most important original minerals in the peridotite appear to have been olivine and phlogopite; the former has been largely altered to serpentine and iron oxides, the latter to vermiculite. Magnetite and perovskite are the most prevalent relict minerals now remaining, but there are also small amounts of apatite, phlogopite and olivine.

MINERALOGY

The coarse fragments and the very fine sand size particles yielded the most satisfactory material for mineral studies. The minerals were studied, primarily, in oils, and all refractive index determinations were made by the immersion method.

Serpentine: Two types of serpentine are present. They probably are antigorite and serpophite. The antigorite occurs as a fine felt of pale green unorientated shreds with greenish yellow, first order, maximum interference colors. Its indices of refraction are: $N_\alpha=1.550$; $N_\beta=1.560$; $N_\gamma=1.560$. These values are somewhat lower than those generally listed, and may be the result of a partial loss of MgO and a gain in H_2O because of weathering. On the other hand they may be normal values for antigorite, for Larsen and Berman[5] list figures that are even lower. Serpophite occurs as pale yellow, structureless, more or less oval masses with either none, or very low first order gray interference colors. Its indices of refraction vary between $N=1.540$ and $N=1.543$. The serpophite appears to correspond very closely with that described by Rogers and Kerr.[6]

The serpentine minerals are found as pseudomorphs after olivine, in irregular masses, or as individual flakes. Some of the pseudomorphs and irregular masses consist of rounded kernels of serpophite in a matrix of antigorite; others contain many inclusions of automorphic magnetite and perofskite; others show smears of yellowish-brown limonite, or contain varying amounts of fine powdery magnetite.

Vermiculite and Phlogopite: Pale yellowish-brown to pale greenish-brown vermiculite occurs as elongated flakes with ragged ends, or as automorphic to hypautomorphic pseudohexagonal crystals. The cleavage flakes have very weak birefringence and yield good negative interference figures; the axial angle varies from 0° to 8°. The average refractive indices are $N_\alpha=1.520$; $N_\beta=1.540$; $N_\gamma=1.540$. The vermiculite is remarkably fresh in appearance, but in places many elongated needle-like crystals of apatite, or occasional crystals of perofskite are distributed throughout it. By count, vermiculite constitutes approximately 32.0 per cent of the very fine sand grade; this figure probably represents very closely the actual percentage of vermiculite in the unseparated material, for rough estimates on the other grades gave values that were similar.

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[5] Larsen, Esper S., and Berman, Harry, The Microscopic Determination of the Nonopaque Minerals: *U. S. Geol. Surv., Bull.* **848,** 152 (1934).

[6] Rogers, Austin F., and Kerr, Paul F., Optical Mineralogy, 362 **(1942)**.

Brown phlogopite occurs sparingly as pseudohexagonal plates up to 3.0 mm. in size. It is negative with an axial angle of 9°. Its average indices of refraction are: $N_\alpha=1.530$; $N_\beta=1.555$; $N_\gamma=1.560$. Many of the phlogopite grains contain inclusions of automorphic apatite.

It is generally recognized that members of the biotite system may change to vermiculite on weathering by loss of alkalies and the addition of water.[7] All of the vermiculite in the dike rock is probably secondary after phlogopite, for many of the phlogopite flakes are bleached in appearance, and have abnormally low and variable indices of refraction, indicating that they are in different stages of alteration to vermiculite.

Olivine: Olivine occurs as very pale yellow, glassy grains that show a branching pattern of curved cracks and break with a conchoidal fracture. They average 1.31 by 0.85 mm. in size, with an occasional grain having a maximum dimension of 2.0 mm. The average indices of refraction are: $N_\alpha=1.663$; $N_\beta=1.678$; $N_\gamma=1.698$. The optic angle is large; it is usually positive, but may be negative.

Considering the advanced state of alteration of the dike, the fresh and unweathered character of most of the olivine grains is remarkable, for there is no evidence of serpentinization or of the formation of secondary iron oxides, even along the abundant curved cracks. The only explanation that suggests itself is that the grains are the remnants of much larger olivine phenocrysts.

Practically all of the olivine, with the exception of highly altered relicts in the phenocrysts of the rock fragments, occurs in the coarse sand grade. Some of these relicts of olivine, because of their optically negative character, were mistaken for hypersthene in the preliminary study. By count, olivine constitutes approximately 5.0 per cent of the coarse sand grade; its volume in the altered dike is computed to be approximately 0.4 per cent.

Perovskite: Small honey-yellow crystals of perovskite with square cross-sections are abundant as inclusions in the serpentine, and somewhat less prevalent in the vermiculite and phlogopite. They vary between 0.03 and 0.005 mm. in size, show very high relief, and have an adamantine luster in reflected light. A few of the larger crystals have very faint interference colors. The automorphic character of the crystals and their occurrence as inclusions in the other minerals strongly indicates that they are primary constituents. They appear to be similar to those first identified and described by Williams,[8] and noted by Smyth,[9] Kemp,[10] and Clark[11] in their petrographic studies of the Syracuse dikes.

[7] Winchell, Alexander N., Elements of Optical Mineralogy, Pt. II, 275 (1933).

[8] Williams, George H., On the serpentine (peridotite) occurring in the Onondaga Salt Groups at Syracuse, N. Y.: *Am. Jour. Sci.*, (3) **34**, 137–145 (1887).

Iron Oxides: Magnetite is present as small crystals, irregular grains, and fine powdery dust. Many of the automorphic crystals occur as inclusions in phlogopite and vermiculite and are undoubtedly primary. Much of the dust and many of the grains are probably secondary from the alteration of olivine, for they are very intimately mixed in with serpentine.

Yellowish-brown limonite occurs as smears and stains irregularly distributed over the surfaces of many of the other minerals, and intimately associated with serpentine. Just how much of it is secondary from the alteration of olivine, and how much has resulted from the weathering of magnetite is not known.

Clay minerals: Distributed throughout the smaller size are pale greenish to colorless microcrystalline aggregates, and extremely fine scale-like individual grains. They have indices of refraction that vary between $N=1.48$ and $N=1.52$. When disturbed in the oils they show flashes of a yellow interference color. No interference figures could be obtained from them. From the data assembled by Rogers and Kerr,[12] they are taken to be montmorillonite. The high moisture content in the chemical analysis is also suggestive of the behaviour of minerals in the montmorillonite group.

Apatite: Needle-like crystals of apatite, $N_\omega=1.635$, were only noted in, or protruding from, fragments and crystals of vermiculite and phlogopite; they represent one of the few original rock constituents.

Chromite: A few small grains of an opaque brownish-black mineral with high index of refraction and submetallic luster in reflected light were taken to be chromite. Chromium in the chemical analysis also suggests this conclusion. The chromite is also probably a relict mineral.

Quartz: A few rounded grains of quartz were noted in the various sand sizes. These probably represent extraneous detrital material. In addition small particles of quartz rather irregular in outline were identified in the silt and clay grade. Some of these may be from disintegrated shale fragments picked up during intrusion of the dike; others may be secondary products produced by hydrothermal alteration or weathering of the original primary silicate minerals.

Andesine: A few angular grains of unweathered milk-white andesine ($Ab_{65}An_{35}$), with N_p on $\{001\}$ and $\{010\}$ cleavages averaging 1.546, were

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[9] Smyth, C. H., Petrography of recently discovered dikes in Syracuse, N. Y.: *Am. Jour. Sci.*, (4) **14** 26–27 (1902).

[10] Kemp, J. F., A newly discovered dike at Dewitt, N. Y.: *Am. Jour. Sci.*, (3) **49**, 459 (1895).

[11] Clark, Burton W., *op. cit.*, 51.

[12] Rogers, Austin F. and Kerr, Paul F., *op. cit.*, 354.

found in the coarse sand and fine sand sizes. It may be one of the original constituents of the rock, but more probably because of its acid character, represents xenolithic material brought from below. Smyth[13] points out that inclusions, both Paleozoic and pre-Cambrian, are prevalent in the Syracuse dikes examined by him.

Tremolite: Three elongated transparent and colorless crystals of tremolite, that showed excellent amphibole cleavage when broken, were found in the 0.5 to 0.25 mm. particles. Careful search of the other sizes failed to yield more material. Index measurements gave: $N_\alpha = 1.600$; $N_\beta = 1.614$; $N_\gamma = 1.625$. Iddings[14] states that tremolite "occurs in serpentine associated with olivine and pyroxene as an alteration product, in peridotites, and in some gabbros." It is probable, therefore, that the tremolite is a secondary product from a pyroxene or related silicate that was originally present in the dike in very small amounts.

Carbonates: A small amount of carbonate, either calcite or dolomite, was detected in the ground mass of some of the rock fragments. Although Winchell[15] points out that the atmospheric weathering of olivine often results in the formation of calcite, showing the removal of magnesium and its replacement by calcium; it is probable that the carbonate is dolomite, for the total amount of calcium in the rock, as shown by the analysis, is relatively low, and most of this is required for perovskite and apatite.

CHEMICAL CHARACTERISTICS

A chemical analysis of the altered dike, with the exception of the determination for manganous oxide, was made by Dr. David S. Morton; the manganous oxide was determined by Dr. Joseph L. Neal. The analysis is given as no. 1 of Table 2. There are also tabulated for comparison analyses of three related peridotites, the average of a number of peridotite analyses, and an early analysis of one of the Syracuse serpentine rocks.

Table 2 shows that the analysis of the Salt Springs Road dike agrees rather closely with the analyses of the Kentucky and Arkansas dikes which contain rather large amounts of mica. The analysis also departs very little from that of the nearby Dewitt dike, which according to Kemp,[16] has much augite as well as mica in it. Furthermore, it does not deviate very much from the average of peridotite analyses as compiled by Grout.[17]

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[13] Smyth, C. H., *op. cit.*, 29.

[14] Iddings, Joseph P., Rock Minerals, 354 (1906).

[15] Winchell, Alexander, N., *op. cit.* 190.

[16] Kemp, J. F., *op. cit.*, 458.

[17] Grout, Frank F., Kemp's Handbook of Rocks, 107 (1942).

TABLE 2. CHEMICAL ANALYSES OF RELATED PERIDOTITES

	1	2	3	4	5	6
SiO_2	36.96	33.84	38.78	38.80	40.67	41.09
TiO_2	2.24	3.78	0.89	1.26		1.16
Al_2O_3	6.16	5.88	6.85	4.16	5.13	4.80
Fe_2O_3	10.60	7.04	8.83	n.d.	8.12	3.96
FeO	2.33	5.16	1.99	8.33		7.12
MnO	0.03	0.16	n.d.	0.13		
MgO	21.30	22.96	26.34	25.98	32.61	32.25
CaO	3.04	9.46	3.88	8.63		4.42
Na_2O	0.25	0.33	0.78	0.17		0.49
K_2O	0.10	2.04	2.56	2.48		0.96
H_2O+	7.12	7.50	7.85	6.93	12.77	3.53
H_2O-	8.50		1.95	0.51		
P_2O_5	0.54	0.89		0.47		0.12
Cr_2O_3	0.33	0.18		0.20		
CO_2	0.74	0.43	0.14	2.95		
BaO	0.02	0.06		0.12		
SO_3	0.03					
S(Sulfide)	0.03					
Cl		0.05				
NiO		0.10		0.09		
	100.33	99.86	100.84	100.22	99.30	100.00

1. Mica-peridotite. Salt Springs Road dike, Syracuse, N. Y. Morton, analyst.
2. Mica-olivinite ("mica-peridotite"). Flanary dike, Crittenden Co., Ky. Hillebrand, analyst. Diller: *Am. Jour. Sci.*, (3) **44,** 288 (1892).
3. Pikeite ("augite-phlogopite-peridotite"). Pike Co., Ark. Brackett, analyst. Williams: *Geol. Surv. Ark.*, Rept. for 1890, II, 383 (**1891**).
4. Mica-augite-peridotite ("limburgite"). Dewitt dike, Syracuse, N. Y. Stokes, analyst. Kemp: *Am. Jour. Sci.*, (3) **49,** 461 (1895).
5. ("Ophiolite"). Syracuse, N. Y. Hunt, analyst. Hunt: *Am. Jour. Sci.*, (2) **26,** 237 (1858)
6. "Peridotites," average composition (mostly after Daly). Grout: Kemp's Handbook of Rocks, 107 (**1942**).

The low K_2O and high H_2O content of the Salt Springs Road material is to be expected because of the weathered and altered character of the dike. The change of phlogopite to vermiculite involves loss of K_2O, and the presence of clay minerals, either of extraneous or secondary origin, requires acquisition of water.

The chemical study verifies the geologic evidence as to the igneous origin of the material, and in conjunction with the petrographic data establishes the rock as a member of the peridotite group.

SPECIFIC GRAVITY

The specific gravity of the altered rock was determined by means of a pyknometer, care being taken to remove all of the air by means of a vacuum pump. An average of 3 determinations gave a specific gravity of 2.70.

CALCULATIONS

For the purpose of classifying the dike on a quantitative and modal basis, the weight percentages of the known component minerals were calculated from the chemical analysis. The formulas and the average specific gravities of the minerals used in the calculations are chiefly from Dana.[18] The formula used for montmorillonite is taken from Rogers and Kerr,[19] and that for vermiculite is given by Gruner.[20] The values for the specific gravities of vermiculite and montmorillonite are taken from Winchell.[21] Calculations were made with a slide rule.

Vermiculite was used as the starting point in the calculations because the individual grains were identified readily and with accuracy. Its frequency percentage, 35.0 per cent, was obtained by counting the grains in the very fine sand grade. This value was taken to represent the relative proportions of vermiculite in the altered rock. This assumption undoubtedly involves some error, but it cannot be very great for approximately the same value was obtained from the disaggregated fine sand size. Knowing the average specific gravity for vermiculite and the specific gravity of the altered rock, the approximate weight percentage of vermiculite was calculated. The weight percentages of the different oxides in vermiculite were then determined from its chemical composition.

The molecular proportions of the other known minerals in the altered rock were calculated from the chemical analysis. All the K_2O was allotted to phlogopite. The excess of Al_2O_3 over that required for vermiculite and phlogopite was assigned to montmorillonite. All the CO_2 was assigned to dolomite. The balance of the MgO, after apportioning the dolomite, vermiculite and montmorillonite equivalents, was assigned to serpentine. All the TiO_2 was allotted to perovskite and all the P_2O_5 to apatite, the excess CaO being apportioned between dolomite and montmorillonite. All the Cr_2O_3 was assigned to chromite, the remaining FeO was assumed to be in magnetite. The excess Fe_2O_3 was assigned to limonite after allotting the equivalent required for vermiculite. The excess SiO_2 was assumed to be present as quartz. The weight percentages of the various minerals in the altered rock were calculated from their molecular equivalents. These values are shown in Table 3.

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[18] Dana's Textbook of Mineralogy, William E. Ford (1932).

[19] Rogers, Austin F., and Kerr, Paul F., *op. cit.*, 359.

[20] Gruner, John W., The structures of vermiculite and their collapse by dehydration: *Am. Mineral.*, **19**, 560 (1934).

[21] Winchell, Alexander N., *op. cit.*, 434.

TABLE 3. MINERAL COMPOSITION OF THE ALTERED ROCK IN WEIGHT PERCENTAGES CALCULATED FROM CHEMICAL ANALYSIS AND PETROGRAPHIC DATA

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	K_2O	Na_2O	TiO_2	P_2O_5	Cr_2O_3	CO_2	H_2O	Sum	Adjusted
Serpentine	12.80				12.56			0.25					3.82	29.43	30.33
Vermiculite	11.54	4.46	1.39		7.71								6.27	31.37	32.23
Phlogopite	0.35	0.11			0.26		0.10						0.04	0.86	0.89
Magnetite			5.02	2.25										7.27	7.49
Limonite			4.19										.74	4.93	5.08
Perovskite						1.57			2.24					3.81	3.92
Chromite				0.08							0.33			.41	0.42
Apatite						0.71				0.54				1.25	1.29
Dolomite					0.34	0.56						0.74		1.64	1.69
Quartz	7.59													7.59	7.82
Clay Minerals*	4.68	1.59			0.43	0.20							1.69	8.59	8.84
Remainder													3.06	3.06	
	36.96	6.16	10.60	2.33	21.30	3.04	0.10	0.25	2.24	0.54	0.33	0.74	15.62	100.21	100.00

* Probably minerals of the montmorillonite division.

The results given in Table 3 must be considered only as approximations, for none of the assumptions can be considered as absolutely correct. They do, however, give a much more accurate picture of the quantitative mineralogic composition of the altered rock than can be obtained from the petrographic and chemical studies alone. The amounts of magnetite and serpentine are a little high, for small quantities of MgO and FeO are required for unaltered olivine. These errors, however, cannot be great for olivine constitutes less than 0.4 per cent of the altered rock. The amount of montmorillonite, also, may be somewhat too high for a small quantity of Al_2O_3 is required for andesine. The adjustment for H_2O is rather large, and may be caused by the variable and high water content of vermiculite and montmorillonite, as shown by the analyses of the former assembled by Gruner,[22] and of the latter assembled by Winchell.[23]

By means of the data assembled in Table 3 and the average specific gravities of the minerals, an estimated mode of the altered rock was calculated in volume percentages. It is tabulated together with the weight percentage mode in columns 1 and 2 of Table 4.

With the aid of certain assumptions, a very generalized mode of the fresh rock was calculated from the mode of the altered rock. The procedures used in the calculations and the assumptions made are as follows:

The relative proportion of olivine was calculated from the volume percentage of serpentine on the assumption that serpentine replaced olivine volume for volume. The relative proportion of phlogopite was found by combining the amount of phlogopite in the altered rock with the quantity of phlogopite calculated from the molecular equivalent of Al_2O_3 in vermiculite. The weight percentages of magnetite, perovskite, and apatite were taken to represent the relative amounts of these minerals in the fresh rock. The clay minerals were considered as impurities and omitted from the calculations. The relative proportions of the various original minerals were then recalculated to 100 per cent. The mode in volume percentages was then calculated from the weight percentages and average specific gravities of the minerals. The mode of the fresh rock, in volume and weight percentages, is given in columns 3 and 4 of Table 4.

The data assembled in Table 4 emphasize the highly altered character of the dike, and contrast rather well the secondary constituents with the primary minerals from which they were derived. Practically all the olivine has been changed to serpentine with the liberation of iron oxides,

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[22] Gruner, John W., *op. cit.* 559 (**1934**).

[23] Winchell, Alexander, A., Montmorillonite: *Am. Mineral.*, **30**, 512 (1945).

TABLE 4. MODES OF ALTERED AND UNALTERED MICA-PERIDOTITE

	Altered Rock		Unaltered Rock	
	Weight percentages	Volume percentages	Weight percentages	Volume percentages
Serpentine	30.4	32.6		
Olivine	—	0.4	44.0	43.0
Vermiculite	32.2	35.0		
Phlogopite	0.9	1.0	43.0	48.0
Magnetite	7.5	4.0	8.0	5.0
Limonite	5.1	3.7		
Perovskite	3.9	2.6	4.0	3.0
Chromite	0.4	—	—	—
Apatite	1.3	1.1	1.0	1.0
Dolomite	1.7	1.6		
Quartz	7.8	8.2		
Clay*	8.8	9.8		
	100.0	100.0	100.0	100.0

* Probably montmorillonite.

and most of the phlogopite has been altered to vermiculite. The only relict minerals appear to be small amounts of olivine, magnetite, perovskite, phlogopite, apatite, and chromite.

GENERAL DISCUSSION AND CONCLUSIONS

The calculated mode, as represented in Table 4, places the unaltered rock in class 4, order 2, family 5 (425) of Johannsen's classification. Because of the assumptions necessary for the calculation of the mode, this conclusion is subject to some revision.

The value for magnetite, 5.0 per cent, just places the rock in order 2. This figure, however, is undoubtedly too high, for relative to the other minerals, it has undergone less loss during weathering. In addition all of the magnetite was assumed to be primary, whereas at least part of it came from the alteration of olivine. The total percentage of ores is, therefore, actually well under 5.0 per cent; consequently the rock should be placed in order 1.

In calculating the serpentine all of it was assumed to have replaced olivine volume for volume. On this basis the value for olivine may be somewhat high, for Harker[24] has shown that the change from olivine to serpentine may produce an increase in volume. On the other hand, any error of this kind is probably more than compensated for by the loss of

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[24] Harker, Alfred, Petrology for Students, 81 (**1923**).

MgO from olivine or serpentine during weathering, for Goldich[25] and others have shown that there is a relatively high loss of this oxide during the weathering of basic rocks. The net result of these discrepancies is that the value for olivine should be somewhat higher; it does not appear from the available evidence that the olivine should be increased to the point where it would be necessary to place the rock in family 1. This possibility, however, should not be overlooked.

The modal values for perovskite, apatite, and probably chromite are also a little too large, for like magnetite, they suffered less loss relative to the other minerals during weathering. The figure for phlogopite probably involves the least error as it was calculated from Al_2O_3, a constituent that is normally considered constant during weathering. Omitting the clay minerals and quartz in determining the mode no doubt introduced some general errors, for some of them may have resulted from the alteration of primary or secondary silicates, or have formed from an original groundmass that at least, in part, may have consisted of glass. None of these discrepancies, however, are sufficiently great to change the class and order of the rock, and it is also doubtful if they have been great enough to change the family.

As a result of a preliminary study, the unaltered dike was thought to contain sufficient hypersthene to be classified as a hypersthene-phlogopite peridotite, and, therefore, it was placed tentatively in family 7 by the authors.[26] This assumption was based primarily on the erroneous conclusion that some of the highly altered relicts of negative olivine in the serpentinized phenocrysts were hypersthene. Careful study of somewhat less altered material failed to confirm the presence of hypersthene; if present in the unaltered rock it probably occurs in only very minor amounts. Consequently, for reasons given in this paper, the rock should be placed in family 5, rather than in family 7.

From the data herein presented, it is concluded that the Salt Springs Road material is the alteration product of an igneous dike of the peridotite group, and until less weathered material is available for study, it should be classified according to Johannsen's classification as a mica peridotite, class 4, order 1, family 5 (415).

ACKNOWLEDGMENTS

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[25] Goldich, Samuel S., A study in rock weathering: *Jour. Geol.* **46**, 54 (1938).

[26] Maynard, James E., and Ploger, Louis W., *op. cit.*, 201 (1946).

OCCURRENCE OF BROMINE IN CARNALLITE AND SYLVITE FROM UTAH AND NEW MEXICO*

Marie Louise Lindberg

Abstract

Both carnallite and sylvite from Eddy County, New Mexico, contain 0.1 per cent of bromine. The bromine content of these minerals from Grand County, Utah, is three times as great. No bromine was detected in halite, polyhalite, långbeinite, or anhydrite from New Mexico. Iodine was not detected in any of these minerals.

On the basis of the bromine content of the sylvite from New Mexico, it is calculated that 7,000 tons of bromine were present in potash salts mined from the Permian basin during the period 1931 to 1945.

Introduction

The Geological Survey has previously made tests for bromine and iodine in core samples of potash salts from New Mexico.[1] Bromine was found to be present in very small amounts. No systematic quantitative determinations were made, nor was the presence of bromine specifically correlated with quantitative mineral composition. Sections of potash core from four recently drilled wells and selected pure saline minerals from Eddy County, New Mexico, together with two cores from Grand County, Utah, were therefore analyzed for their bromine and iodine content. The percentage mineral composition was then correlated with the bromine content. It was found that bromine was restricted to carnallite and sylvite. Iodine was not detected in any of the samples analyzed. If present, its quantity must be less than .005%.

Brine and sea water are the present commercial sources of bromine in the United States, though both Germany and U.S.S.R. have utilized potash salts as a source of bromine.

German potash salts are reported to contain bromine in the following amounts:[2]

Mineral	*Formula*	*% Bromine*
Bischofite	$MgCl_2 \cdot 6H_2O$	0.467
Tachhydrite	$2MgCl_2 \cdot CaCl_2 \cdot 12H_2O$	0.438
Carnallite	$MgCl_2 \cdot KCl \cdot 6H_2O$	0.143–0.456
Sylvite	KCl	0.117–0.300
Sylvinite	$KCl+NaCl$	0.085–0.331
Hartsalz	$KCl+NaCl+MgSO_4 \cdot H_2O$	0.027
Långbeinite	$2MgSO_4 \cdot K_2SO_4$	0.016

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* Published by permission of the Director, Geological Survey, United States Department of the Interior, Washington, D. C.

[1] Schaller, W. T., and Henderson, E. P., Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Dept. Interior. *Geol. Survey, Bull.* **833,** 23 (1932).

[2] Winkler, L. W., The bromine content of German potash salts, original liquors, and end liquors: *Zeit. Angew. Chem.*, **30,** 95–96 (1917) cf. *Chem. Abstracts*, **11,** 2719 (1917).

The first two minerals have not yet been found in any of the potash salts in the United States.

According to Chirkov,[3] bromine and iodine are present in sylvinite from Solikamsk, U.S.S.R., as tabulated below:

Sample	KCl *in sylvinite*	Br *in sylvite*	I *in sylvite*	Br *in halite*	I *in halite*
Sylvite, white	100	0.203	0.0080	—	—
Sylvinite	56.1	0.150	0.0060	0.024	0.0007
Sylvinite	40.1	0.142	0.0055	0.020	0.0009
Halite	0	—	—	0.016	0.0015

Bromine in carnallite from Solikamsk decreases with depth in the bed, from 0.25% at 179.2 meters to 0.07% at the bottom of the bed. Most of the bromine analyses show 0.15 to 0.20% bromine at depths between 200 and 250 feet.[4] A previous article reported the bromine content of Solikamsk carnallites to vary between 0.17 and 0.30%.[5]

The analyzed samples from Utah came from the McCarthy, No. 1 well (McC in Table 1) of the Utah Magnesium Corporation, drilled in the NW ¼ of the NE ¼ sec. 16, T. 22 S., R. 19 E., and from the Wright No. 1 well (W in Table 1) in the SW ¼ of the SW ¼ sec. 4, T. 22 S., R. 19 E.

The analyzed samples from New Mexico were from wells drilled by the Bureau of Mines in T. 20 S., R. 29 E., Eddy County, New Mexico. B M well no. 8 was drilled in section 25, no. 14, in section 26, no. 15 in section 26, and no. 16 in section 14.

The mineralogy of the Utah cores is simple. Halite is the most abundant mineral. It is colorless or gray, medium-grained, and with interlocking grains. Carnallite is also very abundant. Various portions of the core are almost entirely made up of a pale salmon-colored, medium-grained carnallite; less commonly carnallite is colorless or red. Sylvite, which is also abundant in these cores, is usually white, though some fine-grained areas contain red sylvite. The white sylvite occurs as large crystals an inch or more in size, or intergrown with halite in medium-sized grains. Kieserite, anhydrite, and clay were present in small quantities.

The cores from New Mexico contained predominantly colorless halite, brick-red sylvite, and blood-red carnallite, with lesser amounts of pink polyhalite, white kieserite, anhydrite, and red or gray clay.

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[3] Chirkov, S. K., Solid solutions of potassium, sodium, and magnesium halides: *Jour. Gen. Chem.* (U.S.S.R.), **14,** 415 (1944).

[4] Chirkov, S. K., *lit. cit.,* p. 417.

[5] Efreman, N. N., and Veselovskii, A. A., Bromine contents of Solikamsk carnallites: *Jour. Chem. Ind.* (Moscow) **5,** 1365–1369 (1928) cf. *Chem. Abstracts,* **23,** 3191 (1929).

METHODS FOR THE DETERMINATION OF BROMINE

The usual procedure in determining small amounts of iodine and bromine involve oxidizing the iodide and bromide to free iodine and bromine, extracting the free halogens with CS_2 or CCl_4, and matching the colors developed against a set of standards.

In the method of Lane,[6] 1:1 H_2SO_4 and chlorine water are used to oxidize the bromide to bromine. The amount of free bromine is measured in aqueous solution by a photoelectric colorimeter. The presence of iodine interferes with the determination. The quantities of solution used are unsatisfactory for the determination of bromine in saline minerals.

In the method adapted for natural brines by Sweeney and Withrow,[7] H_2SO_4 and chlorine water are used to liberate free bromine, which is extracted in CCl_4 and measured against standards, but no separate test for iodine is made. The quantities of brine and reagent used are unsatisfactory for analysis of bromine in saline minerals.

In the method of Harms[8] NaOCl is used to form free iodine from the iodide. After the iodine has been extracted in CS_2 or $CHCl_3$, an excess of NaOCl is added to form HIO_3 from I_2 and H_2SO_4 is added to liberate Br_2, which, if present, colors the CS_2 or $CHCl_3$ brown.

The method of Harms is the only procedure in which both iodine and bromine are determined. In the samples examined by the writer, it was necessary to test for iodine, though none was found in any of the samples. Therefore, a procedure adaptable to developing the iodine and bromine colors separately in saline minerals was worked out. Concentrated H_2SO_4, in contrast to NaOCl as in the method of Harms, is used to oxidize the iodide to free iodine. After the iodine is extracted and measured, chlorine water is added to oxidize the free iodine to iodate, and the bromide to bromine, which is then extracted in CS_2 and measured against standards prepared in the same way. In contrast to the large volumes used in the procedures of Sweeney and Withrow and of Lane, best results are obtained in this method, when volumes are kept to a minimum.

The following procedure is the one adopted: A one-gram sample of saline minerals is dissolved in 4 ml. of hot water, filtered into a test tube (1.5 cm. in diameter) through a 4 cm. filter paper, and washed once with 1 ml. of water.[9] Three ml. of concentrated H_2SO_4 are added, drop by drop, and the solution corked, shaken, and cooled. One ml. CCl_4 is then added, and the solution again shaken. Any iodine present will color the CCl_4 violet, and the iodine is determined colorimetrically.

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[6] Lane, Marvin, Rapid estimation of bromides in the presence of chlorides: *Ind. Eng. Chem.*, Anal. Ed., **14**, 149 (1942).

[7] Sweeney, O. R., and Withrow, J. R., The chemical examination of natural brines: *Jour. Ind. Eng. Chem.*, **9**, 671–675 (1917).

[8] Harms, F., New method for detecting bromine and iodine: *Zeit. physik. chem. Unterricht*, **42**, 266–267 (1929).

[9] If the volume of the solution should be increased, the amount of H_2SO_4 added to

The iodine is then oxidized to colorless iodate with chlorine water, and an excess of chlorine water is added to oxidize the bromide to bromine. The sample is then shaken to extract the bromine into the CCl_4 layer, and the amber color produced is matched against standards. It is necessary that the standards contain NaCl, since the presence of salt in the core samples tends to suppress the formation of free bromine.

The color of the CCl_4 layer varies with the concentration of chlorine water as well as that of bromine. Insufficient chlorine water does not oxidize all the bromide to free bromine; too much chlorine water oxidizes some of the bromine to bromate.

A series of standards 0.2 mg. apart from 0 to 2 mg. bromine in a gram of NaCl is prepared. The same quantity of strong chlorine water is added to the standards and to the unknowns. The strength of chlorine water chosen develops maximum color in the top range, but oxidizes some of the bromine to colorless bromate in the lower range. After a rough approximation of the bromine content has thus been made, a set of standards 0.1 mg. apart in the range of the unknown is prepared, and the strength of the chlorine water causing maximum depth of color is used in both standard and unknown.

If iodine is present in the unknown, a similar amount should be added to the standard. One-half gram samples should be used instead of gram samples for concentrations above 1.5 mg. of bromine. Results may be duplicated to 0.01% below 0.15% and to 0.02% between 0.15% and 0.30%.

Discussion of Results

The cores from Utah were analyzed for potassium, magnesium, and bromine, and the results tabulated in Table 1 as K_2O, MgO, and Br. Column *A* gives the total per cent of Mg computed to MgO found by chemical analysis. Column *B* gives the per cent of kieserite found by counting grains. Column *C* represents the per cent of MgO in kieserite, calculated from *B*. Column *D* contains the MgO equivalent in carnallite (*A–C*), and column *E* the per cent carnallite calculated from *D*. Column *F* contains the equivalent K_2O in carnallite, calculated from *E*, and column *G* the K calculated to K_2O found by chemical analysis. The

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oxidize iodide to iodine would have to be increased a corresponding amount. However, if it is unnecessary to test for iodine and if the KCl content is very high, the sulfuric acid added in the following step may be reduced to 1 ml. to prevent precipitation of K_2SO_4.

TABLE 1.—BROMINE CONTENT OF POTASH CORES FROM UTAH

	A	B	C	D	E	F	G	H	I	J	K
Depth	MgO equivalent to Mg (Chem. analyses)	% Kieserite (Counting grains)	MgO in kieserite (Calcd. from B)	MgO equivalent to Mg in carnallite (A–C)	% Carnallite to 1% (Calcd. from D)	Equivalent K_2O (Calcd. from E)	K_2O equivalent to K (Chem. analyses)	Difference K_2O (G–F)	% Sylvite to 1% (Calcd. from H)	% Carnallite+Sylvite (E+I)	% Bromine
McC 4658′ 3″–4660′ 1″	11.85	—	—	11.85	82	13.90	13.89	0	0	82	.24
W 4240′ 0″–4244′ 3″	12.52	—	—	12.52	87	14.75	14.81	.06	0	87	.24
W 4232′ 9″–4236′ 5″	8.50	—	—	8.50	59	10.00	16.10	6.10	10	69	.20
W 4245′ 0″–4246′ 9″	9.30	—	—	9.30	65	11.02	13.19	2.17	3	68	.18
McC 4631′ 4″–4635′10″	7.56	—	—	7.56	52	8.82	11.00	2.18	3	55	.16
W 4170′ 0″–4176′ 0″	6.42	—	—	6.42	45	7.63	7.86	.23	0	45	.12
W 4951′ 6″–4954′ 1″	.00	—	—	.00	0	0	26.60	26.60	42	42	.11
McC 4678′11″–4686′ 0″	.08	—	—	.08	0	0	25.25	25.25	40	40	.11
McC 4947′ 7″–4950′10″	4.86	—	—	4.46	31	5.18	6.26	1.08	2	33	.09
W 4149′ 9″–4152′10″	4.86	1	.29	4.57	32	5.43	5.39	.00	0	32	.09
W 4155′ 3″–4158′ 7″	4.94	—	—	4.94	34	5.77	6.14	.37	1	35	.09
McC 4630′ 4″–4631′ 4″	1.07	—	—	1.07	8	1.36	9.83	8.47	13	21	.07
McC 4964′ 0″–4966′ 2″	2.61	—	—	2.61	18	3.05	3.63	.58	1	19	.07
McC 4466′10″–4468′ 8″	1.82	—	—	1.82	12	2.03	7.63	5.60	9	21	.06
McC 4657′ 5″–4658′ 3″	.74	—	—	.74	5	.85	8.56	7.71	12	17	.06
W 4141′ 3″–4144′ 3″	2.35	1	.29	2.06	15	2.54	3.00	.46	1	16	.06
W 4158′ 7″–4159′ 7″	8.59	25	7.25	1.34	9	1.52	6.84	5.32	9	18	.06
W 4631′ 6″–4633′ 2″	.01	—	—	.01	0	0	14.60	14.60	23	23	.06
W 4954′ 1″–4956′ 3″	.00	—	—	.00	0	0	9.56	9.56	15	15	.06
McC 4419′ 9″–4421′ 9″	.02	—	—	.02	0	0	10.19	10.19	16	16	.05
McC 4672′ 0″–4678′11″	.03	—	—	.03	0	0	10.92	10.92	17	17	.05
W 4152′10″–4155′ 3″	1.75	—	—	1.75	12	2.03	2.38	.35	1	13	.05
W 4249′ 2″–4245′ 0″	.28	—	—	.28	2	.34	7.63	7.29	12	14	.05
McC 4660′ 1″–4661′10″	.12	—	—	.12	1	.15	9.14	8.99	14	15	.04
McC 4654′11″–4656′ 9″	.02	—	—	.02	0	0	11.20	11.20	18	18	.04
W 4161′ 6″–4163′ 0″	1.15	3.5	1.02	.13	1	.17	4.93	4.76	8	9	.04
W 4655′ 7″–4658′ 3″	.00	—	—	.00	0	0	14.89	14.89	23	23	.04
W 4658′ 3″–4659′ 6″	.00	—	—	.00	0	0	8.43	8.43	13	13	.04
W 4697′ 9″–4703′ 3″	.00	—	—	.00	0	0	6.60	6.60	10	10	.04
McC 4448′ 6″–4450′ 6″	.13	—	—	.13	1	.16	5.22	5.06	8	9	.03
McC 4661′ 1″–4666′ 8″	.06	—	—	.06	0	0	4.19	4.19	7	7	.03
W 4507′ 4″–4509′ 0″	.01	—	—	.01	0	0	7.96	7.96	12	12	.03
W 4550′ 0″–4554′ 8″	.00	—	—	.00	0	0	8.53	8.53	14	14	.03

difference in K_2O ($G-F$) is listed in column *H*, and the sylvite content, calculated from *H*, is given in column *I*. Total carnallite+sylvite is given in column *J* ($E+I$). The per cent bromine is given in column *K*. Results are arranged in order of decreasing bromine content.

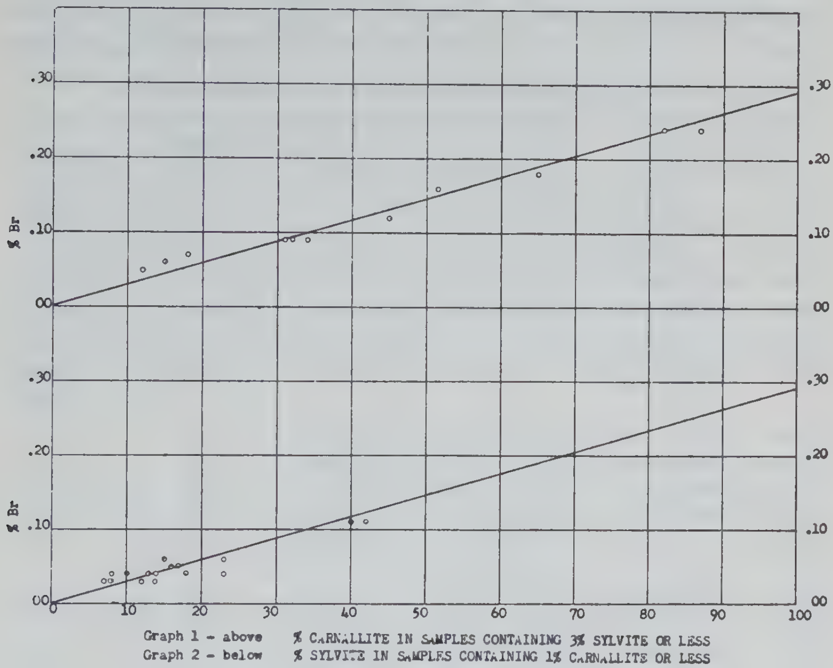

FIG. 1. Bromine content of carnallite and of sylvite from Utah.

The results from Table 1 are presented in Figs. 1 and 2, graphs 1, 2 and 3. In graph 1, the per cent of carnallite in samples containing 3% or less of sylvite is plotted against the bromine content. In graph 2, the per cent of sylvite in samples containing 1% carnallite or less is plotted against the bromine content. In graph 3, the total carnallite plus sylvite (column *J*, Table 1) is plotted against the bromine content. Six samples that are not included in graphs 1 and 2 are included in graph 3. Some of the values in graph 3 are not identical with those in graphs 1 and 2, since the former contains the sum of both carnallite and sylvite, while the latter contains only one mineral plotted against the bromine content.

To obtain a bromine value for 100% carnallite plus sylvite, the average carnallite plus sylvite content was obtained from column *J*, Table 1, and the average bromine content from column *K*, Table 1. The values were computed to 100% carnallite plus sylvite, giving .3% (.29%) bromine. A straight line was drawn from the origin to 100% carnallite plus sylvite—.29% bromine in graph 3. This line was superimposed on graphs 1 and 2. The positions of the points in respect to the line in graphs 1 and 2 definitely show that bromine is equally distributed between carnallite and sylvite, and for every 10% of carnallite plus sylvite, or of carnallite or sylvite alone, the bromine content increases .03% in these

TABLE 2. BROMINE CONTENT OF FOUR NEW MEXICO CORES*

Well and depth	Carnallite	Sylvite	Carnallite +Sylvite	Bromine
B M 8 630′6″–630′10″	55	11	66	.06
B M 8 563′0″–565′6″	53	—	53	.05
B M 15 650′3″–653′0″	60	—	60	.05
B M 14 659′9″–667′4″	5	36	41	.04
B M 15 653′0″–655′4″	53	—	53	.04
B M 8 710′11″–712′0″	1	34	35	.03
B M 14 621′0″–622′4″	3	30	33	.03
B M 15 609′6″–611′0″	8	32	40	.03
B M 16 508′0″–509′5″	3	30	33	.03
B M 16 515′7″–516′7″	—	32	32	.03
B M 8 627′3″–629′8″	3	17	20	.02
B M 8 642′5″–642′11″	1	18	19	.02
B M 8 645′6″–648′8″	2	19	21	.02
B M 8 743′0″–744′4″	—	31	31	.02
B M 14 656′0″–658′0″	20	4	24	.02
B M 14 658′0″–659′9″	15	2	17	.02
B M 15 611′0″–613′5″	10	3	13	.02
B M 8 563′6″–657′0″	8	—	8	.01
B M 8 625′7″–627′3″	9	—	9	.01
B M 8 629′9″–630′6″	10	4	14	.01
B M 8 630′10″–634′3″	2	5	7	.01
B M 8 708′0″–710′11″	1	7	8	.01
B M 8 712′0″–716′0″	1	9	10	.01
B M 14 617′0″–619′9″	1	5	6	.01
B M 14 622′4″–625′6″	6	2	8	.01
B M 15 648′1″–650′3″	1	9	10	.01
B M 16 506′0″–508′0″	—	8	8	.01
B M 16 516′7″–519′4″*	2	5	7	.01

* 26 additional samples from various depths containing between 0 and 6% carnallite plus sylvite, contained a trace of bromine.

two cores. The bromine content of these two wells may be closely approximated if the carnallite and sylvite contents are known.

In the cores from New Mexico are several potassium and magnesium minerals namely, carnallite, kainite, kieserite, polyhalite, and sylvite. The relative proportions of each were found by counting grains of crushed core and allotting the per cent potash found by chemical analysis to the various potash minerals.

Four cores drilled by the Bureau of Mines in New Mexico (holes B M 8, 14, 15, and 16) were analyzed for bromine and the results arranged in Table 2 in order of decreasing bromine content. The percentage of carnallite and of sylvite and of carnallite plus sylvite is tabulated. The values are then plotted in Fig. 2, graph 4. The carnallite-plus-sylvite content and the bromine content were averaged and the bromine value .1% (.093%) obtained by computing to 100% the sum of the carnallite and the sylvite. A straight line was drawn from the origin to 0.093% bromine, and 100% carnallite plus sylvite. The bromine content increases 1% (.093%) for every 10% carnallite plus sylvite in these four New Mexico cores.

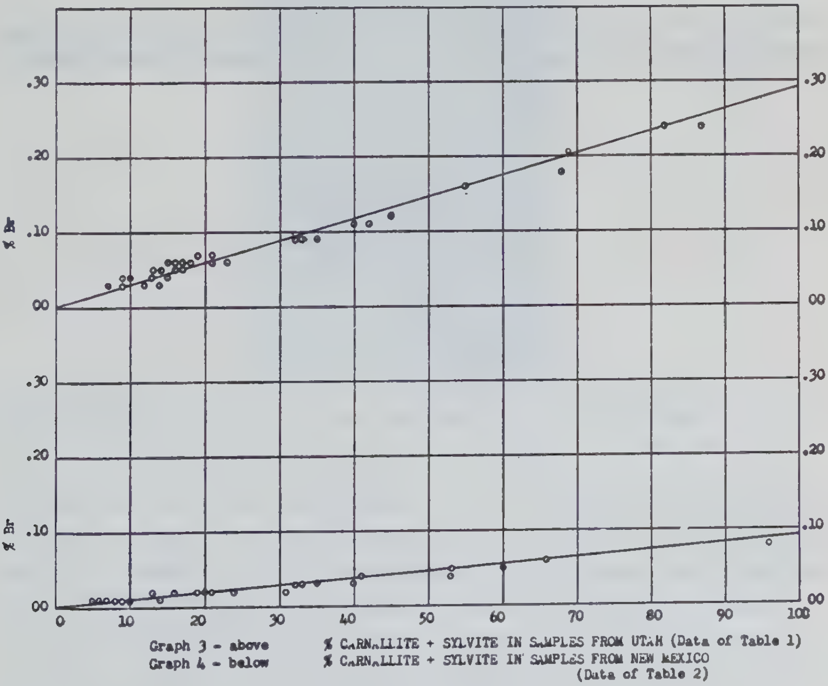

FIG. 2. Bromine content of carnallite plus sylvite, Utah and New Mexico.

No bromine was found in selected samples of apricot halite, blue halite, clear halite, gray anhydrite, and pink polyhalite from the U. S. Potash Company shaft no. 1, Eddy County, New Mexico, nor was any bromine found in långbeinite from shaft no. 2. A sample containing 96% sylvite from shaft no. 1 contained .08% bromine, while the four inch seam of milky white sylvite from bed no. 2 contained .07% bromine. Samples with varying amounts of carnallite contained from .04 to .07% bromine.

Bromine was determined on a sample of pure carnallite analyzed by J. J. Fahey,[10] from Government hole no. 1, Sec. 13, T. 17 S., R. 31 E., depth 933′6″, Eddy County, New Mexico, and .12% bromine was found.

From 1931 to June 1945 four and a half million tons of potash have been mined from the Permian basin. Most of the potash occurs in the mineral sylvite, although some carnallite, långbeinite, and polyhalite may have been included. Computing the tonnage of K_2O to KCl, it is found that 7 million tons of sylvite was mined during this period. On the assumption that sylvite from New Mexico contains .1% bromine, 7,000 tons of bromine was present in potash salts mined from the Permian basin during the period 1931 to 1945.

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[10] Schaller, W. T. and Henderson, E. P., Mineralogy of drill cores from the potash field of New Mexico and Texas: U. S. Dept. Interior, *Geol. Survey, Bull.* **833,** 23 (1932).

NOTES AND NEWS

NOTE ON STRAW-SILICA GLASS FROM CALIFORNIA*

Charles Milton and Norman Davidson

A small fragment, a few grams in weight, of black vesicular glass was received in the Chemical Laboratory of the Geological Survey for identification. Mr. John Davis Buddhue of Pasadena, California, who sent the material, stated (1) that " . . . a small piece of glass (was) found on the surface of a field near Ramona, California. I suspected a haystack fire, but the man who sent it insisted that there had been neither haystacks nor fire near where it was found and that it had not been there when the field was last plowed." It is however certain from the evidence at hand that the specimen does come from a straw or hay-stack fire, although the fire may have occurred many years ago before the knowledge of the present local inhabitants; and the quite stable stony material could well have been buried many years, only recently to be turned up by the plow.

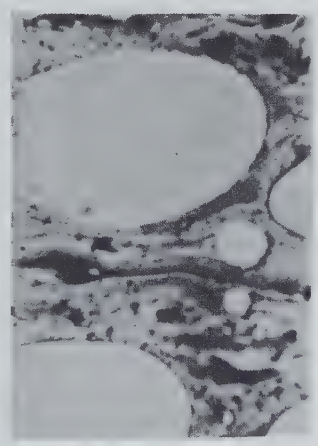

Fig. 1. Microphotograph ×40. Straw-silica glass from Ramona, California. Shows large ovoid and smaller spherical gas vesicles, and linear distribution of carbonaceous particles.

A thin section of the stone shows its highly vesicular character; the vesicles are spherical or slightly ellipsoidal. Usually they are lined with black carbonaceous vegetable debris, which is also strewn throughout the glass. The glass itself is transparent in section, but turbid owing to extremely finely-divided carbonaceous material. It shows flowage, indicated by the turbid streaks, evidently caused by the expansion of the gas of the vesicles—presumably carbon dioxide or monoxide and steam. A few grains of quartz, evidently from the soil, show indications of peripheral fusion or reaction with the molten glass—otherwise, there are no crystallized substances. The index of refraction of the glass is 1.502 ± .003.

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Stones of very similar type have been recognized elsewhere. Mr. Buddhue has called our attention to two Australian occurrences. Charles Fenner (2) describes these as "silica glasses, usually fairly scoriaceous but sometimes massive. The material varies from green to black and smoky gray, and at times is found in large lumps up to 20–30 pounds in weight. Inquiry usually shows that the material has been found on or near the site where a straw stalk has been burnt." Two analyses are given of these Australian stones, I and II below; III is an analysis of the Ramona stone; IV is a synthetic glass (3).

	I	II	III	IV
SiO_2	66.04	57.40	70.11	73.59
Al_2O_3	1.55	1.81	.48	.37
Fe_2O_3	.59	.59	.72	
TiO_2			.04	
MnO			.11	
CaO	6.00	8.56	4.94	6.88
MgO	3.80	5.56	3.36	
K_2O	11.98	13.58	8.76	11.56
Na_2O	6.88	8.98	7.97	7.60
H_2O (110° C.)			.02	
P_2O_5			1.03	
Carbonaceous matter	2.69	3.16	1.88	
	99.53	99.64	99.42	100.00
Refractive index			1.502 ± .003	1.508

I No. 19189 Silica glass from O. B. Flat, South Australia. F. L. Dalwood, analyst. Reference 2 (Fenner).

II No. 19190 Silica glass from Compton Downs, South Australia. F. L. Dalwood, analyst. Reference 2 (Fenner).

III Silica glass from Ramona, California, N. Davidson, analyst.

IV Synthetic (commercial) glass. Reference (Winchell).

These analyses may be compared with those of various straw ashes (4).

	1	2	3	4	5
SiO_2	67.50	47.60	49.27	54.04	51.00
Fe_2O_3	.61	.72	1.91	—	1.13
MgO	2.48	2.45	3.10	2.57	2.58
CaO	5.76	6.89	8.20	8.59	7.22
K_2O	13.65	28.91	22.56	25.07	23.26
Na_2O	1.38	2.69	1.74	.10	3.54
P_2O_5	4.81	5.15	6.53	6.07	4.24
SO_3	2.45	3.13	4.25	3.29	3.87
Cl	1.68	2.19	2.18	—	3.18

1	Winter wheat straw ash	5.37% of dry plant	18 analyses
2	Summer wheat straw ash	4.45% of dry palant	7 analyses
3	Winter rye straw ash	4.46% of dry plant	25 analyses
4	Summer rye straw ash	5.45% of dry plant	4 analyses
5	Summer barley straw ash	5.35% of dry plant	30 analyses

Comparison of the three silica-glass analyses with those of the straw ashes shows a reasonable agreement, with two exceptions. The first is the higher total alkali content in most of the straw ashes. The second is the ten or twelve per cent of $P_2O_5+SO_3+Cl$ reported in the straw ash, but not in the silica stones. The explanation of both discrepancies may be in the stoichometric excess of silica, and the presumably far higher temperature of the formation of the straw-silica glass, as compared to that of the laboratory ashing of the straw. Under natural conditions, the silica would combine with all available basic oxides, displacing the other acidic oxides, which at sufficiently high temperatures will volatilize. At the same time, some soda, as sodium chloride, etc., may be lost.

It may also be noted that the analyses of the straw-silica-stones differ from those of wood ash stones in that these essentially consist of potassium-calcium carbonate. The composition of the straw silica-glass stones, and their peculiar petrographic character, as shown in the illustration, differentiate them from other natural stones, as well as from glasses produced industrially. Fenner points out that the high alkali content of these stones rules out any relation to tektite glasses, as well as to obsidians. In a table listing the composition of some sixteen natural glasses, Morey (5) cites only one whose composition approximates that of the silica stones, this being of "pierres de foudre" i.e., lightning stones "from fusion of grain ash."

In various early editions of Dana's Manual of Mineralogy (6), in particular in the 12th, is an illustration of "Slag from the burning of a stack of wheat straw," showing the characteristic rounded vesicles, but in addition, "good crystals of melilite and tridymite, besides unidentified microlites." Probably a very large stack, burning on a calcareous soil, would permit such crystallization as Dana describes.

Baker and Gaskin (7) have recently described a natural glass from Macedon, Victoria, which in all essential respects they consider similar to Darwin glass (8). Both glasses, after review of the evidence adduced and theories proposed for their origin, are held to have formed from sedimentary material that has been fused at high temperatures lasting for relatively short periods and (with) rapid cooling. Bush fires, with fierce burning of tree trunks holding silica-rich material which was caught up under special circumstances, are suggested as the source of the heat, and of the material fused. It is to be regretted that no analysis of the Macedon glass is given by Baker and Gaskin; however, the analyses cited of the supposedly very similar Darwin glass differ distinctly from those of straw-silica glass. The fifteen analyses of natural glasses, cited by Baker and Gaskin (9) may be plotted, with the three available of straw-silica glass, using as co-ordinates SiO_2, $Al_2O_3+Fe_2O_3$, and $RO+R_2O$. The three straw silica glasses will fall in a sharply restricted field, characterized by extremely low R_2O_3, and fairly high $RO+R_2O$. Fused desert sand is similarly low in R_2O_3, but also equally low in $RO+R_2O$. Fused charcoal slag is intermediate between straw-silica glass and the fused desert sands.

Thanks are due to Mr. J. D. Buddhue, who supplied the California specimen, and to Dr. W. T. Schaller and Dr. M. Fleischer, both of the Geological Survey, for reading and commenting on this paper.

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(2) "Australites Part IV. The John Kennett collection with notes on Darwin glass, bediasites, etc." by Charles Fenner: *Trans. Royal Soc. So. Australia*, **64** (2) 305–324 (1940).

(3) WINCHELL, A. N. The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals, New York **1931** (page 331).

(3) WINCHELL, A. N. The microscopic characters of artificial inorganic solid substances or artificial minerals, New York **1931** (page 331).

(4) WOLFF, EMIL, "Aschenanalysen, II Teil." Berlin (**1880**).

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(7) BAKER, GEORGE, AND GASKIN, ARTHUR T., Natural glass from Macedon, Victoria, and its relationships to other natural glasses: *Journal Geology*, **54**, 88–104 (1946).

(8) *Ibidem*, pp. 88, 95, 103, 104.

(9) *Ibidem*, p. 94.

SPECTROGRAPHIC PROSPECTING FOR BERYLLIUM IN PEGMATITES OF WESTERN MONTANA

Eugene S. Perry* and S. R. B. Cooke†
Montana School of Mines, Butte, Montana.

The wartime demand for beryllium led to widespread search for this rather rare element, and since beryl is the most common beryllium mineral, and as the pegmatite dike is the home of beryl, prospecting for beryllium has been confined largely to pegmatites. Unfortunately the white massive variety of beryl closely resembles certain types of milky pegmatitic quartz, particularly those possessing a rudimentary cleavage or parting. This resemblance, together with close similarities in specific gravity and hardness, places limitations on sight identification of this type of beryl. On the other hand, spectrochemical analysis is unequivocal in detection of beryllium-containing minerals, the only disadvantage being that specimens cannot readily be determined in the field.

During the early days of the war the question arose as to whether some of the hundreds of milky-quartz pegmatites in southwestern Montana might not contain white beryl. Such a question was logical, because commercial quantities of beryl have been found in the Black Hills of South Dakota, near the southeastern corner of Montana, and in Idaho, near the southwestern edge of Montana; and the area between would seem a likely place to search for beryl, particularly since pegmatites are so plentiful in this region. In an attempt to answer this question the writers collected, as part of a Montana Bureau of Mines and Geology program, some fifty samples from pegmatites, most of which consisted of the suspect material, presumably quartz; and spectrochemical analyses for beryllium were made on all samples in the mineral dressing laboratory of the Montana School of Mines.

Although the results of the program were negative as far as the finding of beryllium was concerned, the rather scanty information available on Montana pegmatites has been somewhat augmented; and the project, in a negative sense, has served to delineate areas where beryl may possibly be found.

The pegmatite dikes of southwestern Montana are spread over an area about 100 miles across in each direction, and they are distributed at intervals of perhaps 100 yards up to about one mile. Seldom is their linear extent great; more commonly a width of 5 to 15 feet will continue 200 to 300 feet. Bodies stand vertically, inclined, or lie nearly horizontally. Probably quartz is the most plentiful mineral, but locally feldspar pre-

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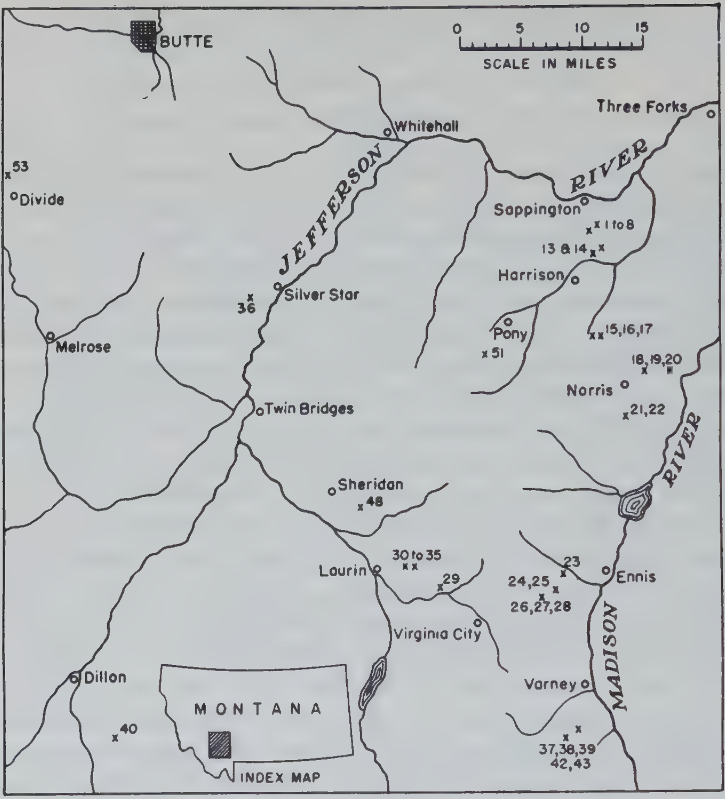

SKETCH MAP
SHOWING PEGMATITE LOCALITIES SAMPLED FOR BERYLLIUM
By
E. S. Perry and S. R. B. Cooke
Montana School of Mines

dominates, and concentrations of muscovite occupy portions of some dikes. Coal-black tourmaline occurs as scattered crystals or irregular masses. Graphic intergrowths of quartz and feldspar are common, and more rarely feldspar and muscovite are intergrown. Other than minerals of the fergusonite and allanite groups[1] rare minerals have not been observed.

The pegmatites of southwestern Montana are believed to be of two distinctly different geologic ages, although superficially they are all similar. Those of older age occur in a complex series of gneisses and schists of Huronian, or possibly Archean age. An upper pre-Cambrian conglomerate (Belt series) lying above the gneiss series contains pebbles and boulders of pegmatitic material similar to that in the dikes, and mainly for this reason the dikes of the gneiss series are considered pre-Cambrian, although they are of later age than the development of the structure of the gneiss.

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[1] Cooke, S. R. B., and Perry, Eugene S., Columbium and cerium minerals in Montana: *Am. Mineral.*, **30**, 623–628 (1945).

The pegmatites of younger age occur in or near late Cretaceous or early Tertiary granitic rocks which form batholithic masses. The minerals of the fergusonite group were found in the older dikes, those of the allanite group in the younger dikes.

Sampling for beryl was confined mainly to the older dikes in the valley of Madison River. Chips of the white mineral resembling white beryl (which eventually proved to be quartz) were broken from the outcrop in ten to twenty places over a distance of 50 to 100 feet, mixed together, and given a number. Only the more conspicuous outcrops were sampled, and many more dikes were passed by than were sampled. All dikes sampled were of the quartz-feldspar type, although several samples were taken in the proximity of mica or tourmaline concentrations, and also close to the occurrences of fergusonite. The region covered is about 50 miles across.

All samples were reduced to 10-mesh, quartered, reduced to 200-mesh, quartered again, and then reduced to approximately 1,200-mesh in an agate mortar. Following careful mixing, a final sample of 15 milligrams was taken for spectrographic analysis.

The samples were volatilized in a graphite arc operating at 150 volts and 12 amperes. Eastman par-speed orthochromatic film was used, and each sample was completely volatilized.

The most sensitive lines of beryllium, those at 3,321.34, 3,321.09, 3,131.07 and 3,130.42 Ångstrom units, were used for identification. Traces of beryllium were detected in the spectra of only three samples, namely samples numbered 1, 42, and 47; the last is not shown on the accompanying map. All other samples gave negative results so far as beryllium is concerned.

For comparative purposes samples of green glassy beryl from Maine, and of white or milky beryl from the Black Hills of South Dakota, were also analyzed. The spectrographic and microscopic analyses of these samples show them to be essentially identical, although the green variety contains slightly more iron than the white variety. Both are uniaxial negative with $\epsilon = 1.575$, and $\omega - \epsilon$ equal to 0.006. Specific gravities of several of the Montana quartz samples were approximately 2.67. The green beryl from Maine has a specific gravity of 2.74, and the white beryl 2.78. The assigned specific gravity of beryl is 2.69 to 2.70, and of ordinary quartz is 2.65.

Conclusion

It is concluded that beryl in recognizable quantities is absent in the early pegmatite dikes lying in the pre-Cambrian gneisses of southwestern Montana, and probably absent in the late pegmatites which accompanied the late Cretaceous or early Tertiary batholithic intrusions characteristic of this region.

Although the gologic history of the early dikes is as yet untold, it now appears that they result from a pre-Cambrian phase of deep-seated igneous activity, later in age than the development of gneissic structure, but earlier than the laying down of the thousands of feet of late pre-Cambrian (Belt) sediments prevalent in southwestern Montana.

A search for beryl in southwestern Montana will probably prove to be a fruitless undertaking, although there is always the possibility that there may be found a more or less isolated area where this rather rare mineral may occur.

PICKING UP GRAINS*

F. C. CALKINS

Picking grains out of oil

Mrs. Lindberg's ingenious method of fishing grains from oil[1] is better adapted to young, deft hands than to old, clumsy ones; mine, at any rate, have not been able to make it work with the straight pipette that she describes. I have had good success, however, with a curved one, somewhat like the "contact pipette" described in connection with another method.[2] In holding a curved pipette, the hand is steadied by resting it on the stage of the microscope, thus obtaining the same advantage that a marksman gets by shooting from a rest.

The ordinary contact pipette, with tip-diameter of 1 mm. or more, will not answer the purpose, as I found out years ago, before learning how to make pipettes that were really slender. The tip of a pipette used for picking up grains ought not to be over 0.5 mm. in outer diameter; the smaller the tip the better the implement works, provided the calibre is large enough to admit the desired grains without jamming. It is possible to make a pipette with a tip as little as 0.2 mm. in diameter, but one so slender as that is extremely fragile, and a tip diameter of 0.4 mm. is generally small enough. For ease of manipulation, the drawn-out part of the finished pipette should not be more than 5 cm. long, and the main body not less than 9 cm.

The implement can be made as follows. One end of a piece of thin-walled tubing, about 5 or 6 mm. in diameter and 10 or 11 cm. in length, is softened in a Bunsen flame and drawn out. This operation is repeated once or twice, so that the thickness will diminish abruptly. The drawn-out part is then broken off about 6 cm. from the shoulder, and, while the tube is held in a clamp at an inclination of 45°, the bend is made by momentarily applying heat at the chosen point with the flame of a match. Finally the end is broken square across, about 5 mm. from the bend, on a fine scratch made with a chip of quartz.

A sleeve of soft rubber tubing may be slipped over the butt end of the tube, beyond which it should project about 3 or 4 cm. This sleeve is not absolutely necessary, and it need not be closed at the end.

When the pipette is about to be used, it should be allowed to imbibe as much clean oil as it will when rather steeply inclined; for if the tip is inserted amidst the grains when the pipette is empty, a strong current is set up that may quickly sweep in many grains at once. The desired grain had better be isolated by means of a mounted needle, and the tip of the partly charged pipette placed immediately to its right; one can then see the grain slide into the tube. If the tip is now brought into close contact with a dry part of the slide and raised, a droplet of oil will be left, and this droplet, or the second or third similarly formed, is likely to contain the captured grain. If the grain fails to appear, or if several grains have been captured, the catch may be retrieved by expelling the oil. This can be done by blowing, but a tidier method is to fold and pinch the rubber sleeve. If the bend near the tip points down during this operation, the expelled oil will hang from it, and can be gently deposited on a slide, with the captured grains huddled in its midst.

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[1] Lindberg, Marie L., A method for isolating grains mounted in index oils: *Am. Mineral.*, **29**, 323–324 (1944).

[2] Calkins, F. C., Transfer of grains from one liquid to another: *Am. Mineral.* **19**, 143–149 (1934).

Most of the oil can then be removed with the same pipette or with another of the "drinker" type,[3] and the remainder pushed aside, as Mrs. Lindberg advises,[4] with acetone. This can be done conveniently by bringing a contact pipette charged with acetone several times in contact with the slide close to the grains. To avoid any contamination of the new oil with a remnant of the old, the grains may be transferred to the new oil by means of the mounted needle, to which they will readily adhere if it is coated with the thinnest possible film of oil. Several grains at once can be picked up in this way, and if, as often happens, a few unwanted grains have been captured, they can be left behind.

A curved pipette, even in a none-too-steady hand, will pick up a chosen grain as little as 0.05 mm. in diameter. But my "grain-lifter"[5] will do the same thing, usually in less time, and, unlike the pipette, will pick up only the grain that is wanted. A lifter can be made more easily than a very slender pipette; the simplest way to make one is to stick a bit of wire or a small needle into a wooden handle, bend it down (a needle must first be slightly detempered), and grind a sole on the end. In this form the lifter is almost indestructible, whereas a suitable pipette is more or less fragile. The other pipettes, which may be 1 mm. or more in tip-diameter, are easily made and not too easily broken. The lifter method, therefore, still seems worthy of consideration, especially with certain improvements made since it was first described.

One "bug" in the lifter method was the fact that neither vaseline nor balsam could be used in oils of high refractive index, which rapidly dissolve both. (The amount of vaseline dissolved in other oils is so small that its effect on refractive index is negligible.) Mucin, gotten by touching the sole of the lifter to the tongue, works in oils of high index, and also in most others, but it cannot be removed with xylol. It can be washed away, however, with acetone, once the grain is detached from the lifter. Relatively large, thick grains usually come off when brought in contact with a dry part of the slide, but a thin, flat grain may adhere tenaciously. This difficulty can be obviated by using glycerine, which will serve as the adhesive in all oils but those that contain alcohols; in such oils glycerine, and also mucin, is somewhat soluble. The charge of glycerine must be extremely small; enough is taken up by barely touching the sole of the lifter to a film or droplet of the liquid. If a grain picked up with glycerine is not readily detached, the oil can be washed off in a droplet of xylol and the grain then freed by immersing it in a tiny droplet of glycerine, which can be washed away with acetone.

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[3] Calkins, F. C., *op. cit.*, p. 145, fig. 1*C′*.

[4] Lindberg, Marie L., *op. cit.*, p. 324.

[5] Calkins, F. C., *op. cit.*, p. 145, fig. 1*d*.

Vaseline may be used in oils of low index, and optionally in oils of moderate index. The cleaning process formerly described[6] can be shortened. A single droplet of xylol will not only release the grain but leave it almost clean; the cleaning can then be completed with acetone and the grain transferred in the manner described above.

At least nine times out of ten the lifter method, with mucin as the adhesive, will do the work. If thin flakes or very fragile grains are to be picked out, the pipette method is the better; and I hope this note will make it more widely available to young and old.

Needle chisels

Adherence of dry particles to an oiled surface can be utilized in taking a small sample from any megascopic grain in a hand specimen. This can be done, without multilating the specimen, by means of a chisel consisting of a piece of a heavy darning needle set in a stout wooden handle. It is convenient to have the bit set at an angle of about 30° to the axis of the handle; a blunt edge is then made by grinding a bevel normal to that axis. If the bit, thinly coated with oil, is pressed against the grain and given a rocking motion, most of the fragments detached will adhere, and they will be released when the bit is dipped in a droplet of oil. Or if the chisel is immersed in a large droplet of xylol dipped up in a wire loop—which, in order to take a full charge, should be horizontal when dipped and be raised quickly—the grains will collect in the bottom of the droplet. If the droplet is then touched to a piece of absorbent paper, white or black according to whether the mineral is dark or light, the xylol will sink in, and the grains, virtually free from oil, will be left in a shallow heap, from which a few at a time can be transferred with a needle to various oils. A good background for light-colored grains is afforded by the black paper used in making photograph albums.

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[6] Calkins, F. C., *op. cit.*, p. 149.

This heavy chisel is of course an adaptation of the small needle-chisel used by Short[7] for digging samples from polished sections. Short's chisel apparently has the bit in line with the handle, but when the bit is set at an angle it cuts better, and is also less liable to break. Murdoch[8] recommends a needle set at an angle of 30° for testing hardness. A very small needle chisel can be used for digging out a grain, or part of one—e.g. the core of a plagioclase crystal—from a thin section.

Magnetized needle

A thick permanently magnetized needle will pick grains of magnetite, and small ones of pyrrhotite, out of oil. It can also be used for distinguishing magnetite, pyrrhotite, and pyrite from one another in a covered oil mount: if the needle is slid about on the cover glass, magnetite grains will follow it, while pyrrhotite will only stir a little and pyrite will remain motionless.

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[7] Short, M. N., Microscopic Determination of the Ore Minerals: *U. S. Geol. Survey, Bull.* **825**, p. 119, fig. 11 (1931).

[8] Murdoch, Joseph, Microscopical Determination of the Ore Minerals, p. 29, fig. 7 (1916).

ADDITIONAL DATA ON BRAZILIANITE

Cornelius S. Hurlbut, Jr. and Elizabeth J. Weichel,
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Brazilianite, the new phosphate, $Na_2Al_6P_4O_{16}(OH)_8$, is described by Pough and Henderson* as follows: monoclinic, $\beta = 97°22'$, perfect {010} cleavage; specific gravity 2.94; axial ratios $a:b:c = 1.1056:1:0.6992$.

Dr. Pough sent several small crystals of brazilianite to the Department of Mineralogy at Harvard University for x-ray analysis. The following data obtained on them are presented to make the description of the mineral more complete.

Two sets of rotation and Weissenberg photographs were taken (1) on a small fragment mounted so that the axis of rotation was normal to the {010} cleavage; (2) on an elongated crystal rotated about the axis of elongation, which proved to be [101]. From the Weissenberg photographs (about [010]) $d_{001} = 7.00$ Å, $d_{100} = 11.10$ Å, (about [101]) $d_{010} = 10.08$ Å. Using Pough and Henderson's $\beta = 97°22'$ the cell dimensions are $a_0 = 11.19$ Å, $b_0 = 10.08$ Å, $c_0 = 7.06$ Å. These give the axial ratios of $a_0:b_0:c_0 = 1.1102:1.0.7004$, which is in good agreement with Pough and Henderson's morphological ratios and validates their choice of the unit form.

The extinction criteria determined from the Weissenberg photographs conform to the space group $P2_1/n$.

The specific gravity of three small fragments (15–20 milligrams) of brazilianite was determined on the Berman density balance. Two of these gave a value of 2.977 and the third 2.975, slightly higher than that given by Pough and Henderson. Using the lattice constants given above and the deduced cell content of two molecules to the unit cell, the calculated specific gravity is 3.025. This is in closer agreement to our value than 2.94 given by Pough and Henderson.

Optical properties

The indices of refraction given by Pough and Henderson were confirmed and in addition 2V and the optical orientation were determined on the universal stage.

	n_{Na}	
$X = b$	1.598	Biaxial (+)
$Y \wedge c = 15°$	1.605	$2V = 80°$
Z	1.617	$r < v$, weak

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* Pough, Frederick H., and Henderson, Edward P., Brazilianite, a new phosphate mineral: *Am. Mineral.*, **30**, 572–582 (1945).

PROCEEDINGS OF SOCIETIES

ABSTRACTS OF PAPERS PRESENTED AT THE SPRING MEETING OF THE CRYSTALLOGRAPHIC SOCIETY AT SMITH COLLEGE MARCH 21–23, 1946

TYPES OF ORDER IN PROTEIN FIBRILS

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Evidence concerning the structure of certain animal protein fibrils reveals two more or less independent types of order in the arrangement of the constituent amino-acid residues: (1) a limited amount of structural regularity in the immediate neighborhood of individual residues, and (2) a surprising degree of order in the overall disposition of the residues, extending through large distances (hundreds of A) and specific for each protein. In the best known cases, collagen and paramyosin, the repeating large units of structure are, respectively, one- and two-dimensional in character. The remaining (transverse) dimensions of these fibrils apparently lack order of large size.

Structures of this type, which possess regular order in less than three directions and whose randomly constructed remaining dimensions are not too thick, should yield diffraction over a wide range of angles of incidence of the x-ray beam. The true fiber-axis spacings in such cases are given by $d_{\mathrm{Bragg/cos}\ oc}$, where d_{Bragg} is an apparent spacing calculated using the Bragg Law, and *oc* is the angle of departure from perpendicularity between x-ray beam and fiber axis. This relationship has been observed for myosin and collagen specimens.

THE LATTICE IN CRYSTALLOGRAPHY

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The lattice is a geometrical concept which would be very useful in crystallography even if crystals had not been found to possess their triperiodic structure. Independently of any structural hypothesis, the primitive lattice built on the relative unit lengths obtained by goniometry enables one to give the fundamental laws of crystallography a most vivid expression: (1) *Faces* (and the other planes that are the evidence for the discontinuous vectorial properties) *are parallel to families of nets* (=Law of Constancy of Angles). (2) *These families of nets are among those characterized by large interplanar distances* (=Law of Small Rational Indices). If extinctions are taken into account—lattice extinctions due to various centerings and space-group extinctions due to the symmetry of the motif (cell content)—a lattice and an aspect (corresponding to one or several space-groups) can generally be found such that (3) *the families of nets parallel to which faces occur are precisely those with the largest effective interplanar distances and the larger this distance the more important the corresponding face* (=Generalized Law of Bravais, which coincides with the Classical Law of Bravais in the absence of glide-planes or screw-axes of symmetry).

The lattice was also made to express the triperiodicity of the crystal structure, at a time when such periodicity could only be postulated (*reticular hypothesis*). Haüy's concept of "decroissance" was in fact the first reticular hypothesis, his "formes primitives" being the cells of seven primitive lattices. Bravais postulated physical reality for his fourteen lattices. Friedel showed that the nonexistence of irrational three-fold axes of symmetry was, at the time, the only justification for the reticular hypothesis, since such axes are compatible with the Law of Small Rational Indices but are impossible in a lattice. X-ray diffraction proved the reticular hypothesis, previously based on negative evidence, and definitely established that irrational 3-axes would never be found in crystals.

The lattice determined from the Classical Law of Bravais has been called the *morphological lattice* (or Haüy-Bravais lattice) to stress the fact that, in many cases, it did not coincide with the *structural lattice* found by x-ray diffraction. In view of the generalization of the Law of Bravais, this distinction has lost most of its significance.

The first reciprocal lattice was Bravais' "reseau polaire." Subsequent varieties differ only as to scale. V. Goldschmidt's "Polarform" was the cell of a primitive reciprocal lattice, as Haüy's "forme primitive" was the cell of a primitive direct lattice. The reciprocal lattice is the tool par excellence for the analysis of crystal morphology as well as for the x-ray investigation of crystal structure by Ewald's method.

EXPERIMENTAL STUDY OF THE CHANGE IN HABIT OF SODIUM NITRATE CRYSTALS GROWN FROM WATER SOLUTION

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The mechanism of the change in habit of a growing crystal due to the presence of impurities in the solution is usually considered from the point of view of the effect of distortion introduced on the surface of the crystal by the implanting of the impurity particle. This mechanism requires, among other things, a relationship between the size of the impurity particle and the dimensions of the crystal structure. A study of the behavior of sodium nitrate crystals (rhombohedral, isostructural with calcite) yields new information, but still not enough to completely elucidate the mechanism. Iodides produced an effect that varied with the cation, LiI having the least effect, and NH_4I the greatest. A large variety of other cations and anions gave negative results. The effect of hydroxyl was profound, producing great distortion, and in high concentration, effecting a complete change of habit. The prevailing theories are applied to these observations as far as possible. Experimental work on sodium nitrate is limited by the great solubility of this salt.

CRYSTALLOGRAPHY, A COMMON GROUND IN MANY SCIENCES

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Brooklyn Polytechnic Institute.

The scientific study of crystals may be said to have started in the latter half of the 18th century with the introduction of the goniometer, although the constancy of interfacial angles was known at an earlier time. Haüy enumerated the Law of Rational Indices and made a thorough study of crystals found in nature (minerals). Particularly with the development of the polarizing microscope, crystallography took a firm place as a tool in chemistry. Biology too proved an attractive field to apply the ideas of crystallography. With the discovery and development of x-ray diffraction an entirely new world of structural studies was opened and very rapidly the old fields and many new ones like metallurgy were invaded. The influence of crystallography in all these fields was great but perhaps the reaction on crystallography was even greater. The interesting materials often proved to be not the perfect crystals that delighted the early crystallographers but rather the imperfectly organized structures of metallurgy, biology and even mineralogy. The crystallographers of today can no longer pun as Tutton did that "unlike women, the beauty of crystals lies in the planeness of their faces."

TWINNING IN LEADHILLITE

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A recent find of leadhillite crystals at the Mammoth Mine, Arizona, showed three types of crystals in a single vug: I. bipyramidal (trigonal, uniaxial "susannite"); II. prismatic crystals composed of biaxial sectors of monoclinic symmetry, but resembling aragonite sections in twinning; and III. pseudo-rhombohedral or tabular crystals composed of 2, 3, or 6 individuals, twinned according to the Artini law.

GRAPHICAL SUMMATION OF FOURIER SERIES IN CRYSTAL STRUCTURE ANALYSIS

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Massachusetts Institute of Technology.

The contribution of each plane to the electron density throughout the projected unit cell is in the form of a cosine surface whose shape depends only on the geometry of the plane. The amplitude of the surface only is a function of crystal structure. Graphical computation of the product of F or F^2 by the cosine function can be accomplished rapidly by use of a cosine curve and a variable scale. If the points in the unit cell for which computation is to be made are located by a semi-polar coordinate system, the form of the computations is considerably simplified and the Fourier series reduces to the following form

$$\rho_{(x,c)} = \Sigma\Sigma F_{(hk0)} \cos \frac{2\pi x}{N} K$$

where x is an integer from one to N and K is a constant whose value depends on the indices and the slope of the line from the origin to the point. With the computations in this form, it is possible to sum the entire series using one curve, one compact table and a scale. The scale is variable and can be adjusted for any F or F^2 value from one to one thousand. The contributions of a reflection to all of the points along a given radial line can be computed and recorded in a minute or less. The electron density of diopside projected on (100) has been computed using this method and was found to be identical with published diagrams.

CRYSTAL PATTERN SYNTHESIS BY AN APPROXIMATE SUMMATION OF FOURIER SERIES

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Massachusetts Institute of Technology.

An accumulation of electron density in a projected unit cell can occur only when the positive solutions of the Fourier series exceed the negative solutions. A large peak can occur only when most of the planes, $hk0$, are contributing nearly their maximum amplitudes. This suggests that a faithful indication of the positions of important peaks might be obtained quickly by determining for each point in the cell the difference between the sums of the maxima and minima which occur at each point. Since the maxima and minima do not, in general, fall on the points of the coordinate system, it is necessary to assume that a plane contributes its full amount when its amplitude is within a certain amount of the maximum. Fifty per cent has been chosen arbitrarily as the amount. Similarly, the plane is assumed to subtract its full amount when fifty per cent or more of its minimum. Using this concept, it is possible to perform an approximate summation with no computations other than addition. In the approximate summation of the density of diopside projected on (001), estimated intensities were found to give peak parameters which compare favorably with those obtained when the complete summation is performed in the conventional manner. The approximate method, although perhaps not to be trusted in actual structure analysis, can be used to eliminate areas where atoms will not be found and as a guide in deciding if an assumed structure is possible.

THE USE OF SAND IN MAKING FOURIER PROJECTIONS OF CRYSTAL STRUCTURES

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This paper presents a method of using sand in building models of two dimensional Fourier projections in crystal structure analysis. The machine for producing these models is described and the results are illustrated by projections of known structures.

The mathematical principle of this method of summing Fourier series is identical to that which Bragg[1] developed in England and which Huggins[2,3] so ably perfected in this country. The chief difference is in the use of sand instead of photographic film as the medium for producing contrasts in electron density throughout the projection.

When a diffraction pattern of a single crystal is taken on any of the moving film types of cameras, each spot presents three measurable parameters: two of position and one of density. These three parameters may be used to calculate three corresponding parameters: (*a*) the interplanar spacing, (*b*) an angle which might be called ψ and (*c*) the structure factor. Since it happens that each term in a Fourier series (as used in crystal structure work) is the equation of a two-dimensional wave having four properties (a^1) wave length, (b^1) direction, (c^1) amplitude, and (d^1) phase, and since there is a one-to-one relationship between a, b, c and a^1, b^1, and c^1, it follows that aside from (d^1) the diffraction pattern furnishes all the data that is desired for making a Fourier projection. It only remains to find means of assimilating the proper wave for each term in the series and means for adding the waves. In the Bragg method the waves were represented by sinusoidal transparencies having two properties (*a*) wave length, which corresponded to interplanar spacing, and (*b*) direction. These waves are added photographically and the third property (*c*) or amplitude of each wave is related to the time of exposure.

In the present method the waves are produced by mechanically spreading sand into a grid from a moving hopper. The hopper has a sinusoidal template below it which causes a wave-like distribution of sand; the wave length of this template corresponding to the interplanar spacings of the crystal with a scale of one centimeter per Angstrom. The angle is adjusted by rotating the collecting grid, and the amplitude is established by the rate by which the sand is mechanically driven from the hopper. The phase is controlled by shifting the collecting grid the proper fraction of a wave length perpendicular to the direction of the wave crests. The electron density at any point in the projection is proportional to the elevation of sand in the corresponding point in the grid. The simple method for photographing the result is described.

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[1] Bragg, W. L., *Zeits. Krist*; **470,** 475 (1929).

[2] Huggins, M. L., *J. Am. Chem. Soc.*, **63,** 66 (1941).

[3] Huggins, M. L., *J. Chem. Phys.*, **12,** 520 (1944).

VARIATION IN CRYSTAL HABIT OF PYRITE IN THE COLLINS HILL PEGMATITE NEAR MIDDLETOWN, CONNECTICUT

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The pegmatite on Collins Hill has been worked chiefly for feldspar during the past several decades and for 15 years the writer has collected specimens from the dumps of waste material containing small pyrite crystals from microscopic size up to a quarter of an inch through the crystals.

The crystals usually occur in the small cavities and are associated with a variety of minerals or they may be located in the polyhedral cavities of cleavelandite.

The crystal forms are sometimes unmodified cubes or octahedrons or a combination of these. In some cavities the crystals in addition to the cube and octahedron are modified by the pyritohedron, trisoctahedron and dyakisdodecahedron. The more complex crystals are associated with calcite which is encountered usually in crystals but occasionally in masses partly filling some of the cavities.

The minerals usually associated with the pyrite in various amounts and combinations are fluorite, cookeite, lepidolite, albite, quartz, various multi-colored tourmalines, siderite, bertrandite, beryl, apatite, etc.

CRYSTALLOGRAPHY OF THE SEVEN MODIFICATIONS OF SILICON CARBIDE

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In 1928 Ott, entirely from x-ray studies, described a modification of silicon carbide containing 17 formula weights in the rhombohedral unit cell, and designated it type V. During the author's comprehensive study of the crystallography of SiC (*Am. Mineral.*, **29**, pp. 249–278, 327–362, 1944), this modification was not encountered. Recently, however, a large crystal of this type was found, and studied by optical and x-ray goniometrical methods. The results of this investigation were outlined, and a comparison made with the other six known modifications of this compound.

Alpha-SiC, type V, is ditrigonal pyramidal, $c:a=41.71:1$, yielding a simple arithmetical series of forms characteristic of crystals with rhombohedral lattices. Equi-inclination Weissenberg studies indicated a rhombohedral unit cell containing 17 formula weights; space group, $R3m$. Referred to hexagonal axes: $a_0=3.073$Å, $c_0=128.17$Å. An x-ray powder photograph showed a unique pattern, but some of the lines were precisely or nearly equivalent in position to certain lines in the powder photographs of the other SiC modifications, particularly type VI.

PLASTIC DEFORMATION AND RECRYSTALLIZATION OF NON-METAL CRYSTALS

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Experiments have been carried out on plastically deformable substances to determine the effect of deformation on recrystallization. The basis for this work is the theory that increased energy due to plastic deformation, promotes recrystallization and grain growth.

Fluorite and anhydrite were chosen as experimental materials because structurally they possess a large number of glide planes.

Pressures of the order of 10,000 atmospheres have been used to compress the powdered minerals which were subsequently heated at temperatures below the melting point. The rate of grain growth is found to increase with temperature as demonstrated by measurement of grain sizes of polished sections.

X-ray patterns proved that increased strain reduces the temperature at which recrystallization starts, which is in accord with the proposed theory. It is concluded that for each substance there is a critical recrystallization temperature dependent on initial molding pressure.

Time has been found to be of secondary importance in affecting the critical temperature of recrystallization.

OPTICAL ACTIVITY IN CRYSTALS: CRYSTALLOGRAPHY OF *l*-CYSTINE

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Optical activity along axes of optical isotropy can be detected in some transparent crystals with relatively simple optical systems available to many crystallographers. The presence of optical activity in a given crystal is a help in choosing or confirming its symmetry class and space group, where morphology and *x*-ray diffraction alone are often inadequate.

A new tetragonal crystal form of the amino-acid *l*-cystine, whose solutions have a large levo rotation, is reported and its lattice and optical constants are set out in a table along with those of the previously known hexagonal form of the same substance. The two crystals are shown to have opposite rotations along their isotropic axes, the hexagonal crystal has a levo rotation of about 18° per mm. while the tetragonal crystal has a dextro rotation of about 25° per mm. for white light.

BIOLOGICAL PROBLEMS AND CRYSTALLOGRAPHIC PRINCIPLES

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A number of "structural" problems are of basic importance for biology, physiology and medicine. Foremost among these is the nature of protein synthesis. The suggestion is put forward that synthesis is a question of orderly propinquity. The problem is therefore discussed in the light of the application of crystallographic principles to arrangements of molecules in orderly propinquity, i.e. molecular crystals. A possible mechanism of synthesis is proposed for consideration. It is explained in terms of the crystal which seems most illuminating, namely the 5-hydrate of phosphotungstic acid, which has the space group O_h^4. Reference is also made to the crystal of hexamethylene tetramine. According to this picture, the autocatalytic native protein is necessarily a surface structure built on a framework of high symmetry: further the surface is self-complementary in a crystallographically satisfactory sense. The self-complementarity of a surface resides in the complementarity of pairs of fragments of the surface and it is not justifiable or indeed necessary to assume the self-complementarity of all the individual fragments. The far-reaching implications of this viewpoint are indicated and a brief account of the essential importance of crystallographic ideas and principles in a wide variety of biological structure problems is given.

NEW MINERAL NAMES

Mahadevite

S. Ramaseshan, Mahadevite—a new species of mica. *Proc. Indian Acad. Sci.*, **22A,** 177–181 (1945).

Physical Properties: Luster vitreous. Thick sheets are bronze-colored and nearly opaque, thin flakes are transparent, greenish-yellow. Cleavage highly perfect, producing thin elastic laminae. Pleochroism higher than that of muscovite, much less than that of biotite.

Optically negative, acute bisectrix practically normal to the plane of cleavage. 2E = 13°48′. Interference figures show that the plane of the optic axes is at right angles to the plane of symmetry, whose position was determined from percussion figures.

Chemical Properties: Analyses gave: SiO_2 38.98, 38.24; Al_2O_3 29.94, 29.20 (including $TiO_2+Mn_3O_4$, not separately determined), total iron as Fe_2O_3 4.12, 3.86; MgO 13.2, 14.4, CaO 0.49, 0.50, alkalies (not stated whether as Na_2O or K_2O) 9.6, 9.2, H_2O 3.8, 3.8, F not detd.; total 100.13, 99.20%

This is intermediate between muscovite and phlogopite in composition.

Occurrence: Occurs in a pegmatite in mica schist on a hill called Racha, Konda, eastern Warangal district (Hyderabad ?), India.

Name: For C. Mahadevan, who found the mineral.

Michael Fleischer.

Zirfesite

E. E. Kostyleva, Zirfesite—a new zirconium mineral of the zone of hypergenesis. ***Compt. rend. acad. sci. U.R.S.S.***, **48,** 502–504 (1945).

Physical Properties: Pale yellow, light in weight, powdery, smeary, sticking to the tongue, with a faint smell resembling that of clays. Careful examination by eye or under the microscope shows flakes and lamellae with pearly luster. Optically isotropic, $n = 1.620$.

Chemical Properties: Analysis by L. B. Tumilovich gave: SiO_2 21.27, TiO_2 0.96, ZrO_2 30.47, Fe_2O_3 14.27, Al_2O_3 1.63, rare earths 2.12, $(Ta, Cb)_2O_5$ 2.40, FeO none, MnO 0.24, CaO 0.14, MgO 0.57, Na_2O traces, K_2O 0.21, H_2O- 16.17, H_2O+ 9.66; sum 100.11%. This corresponds to $(ZrO_2, Fe_2O_3) \cdot SiO_2 \cdot nH_2O$. The mineral is readily soluble in dilute HCl and the solution gelatinizes if heated. Treatment with 5% Na_2CO_3 on the water bath extracts a significant amount of SiO_2. Tartaric acid dissolves an appreciable quantity of Fe and Zr. The mineral loses 20.96% H_2O at 135°, 23.56% at 200°, all H_2O at 300°.

Thermal Analysis: The mineral gives an endothermal reaction at 135° and a subsequent small exothermal rise. It shows a sharp exothermal break at 700°. It thus resembles allophane in behavior. At this temperature, melting takes place and a new, brick-red phase is formed, insoluble in HCl, with $n = 1.720$.

Occurrence: An alteration product of eudialyte at Mannepachk, Khibina Tundras, Kola Peninsula.

Name: From the principal elements, Zr, Fe, Si.

M.F.